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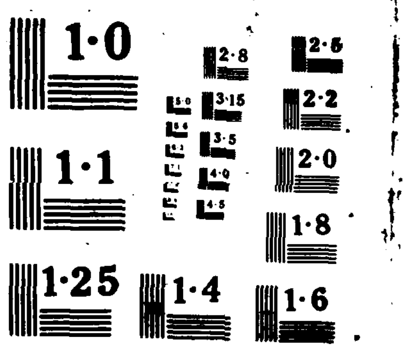
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SELECTION OF PACKET SWITCHED FACILITIES FOR THE SEARCH AND RESCUE COMMUNICATIONS NETWORK BASED ON PERFORMANCE

by

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B.S., United States Air Force Academy, 1978

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A project submitted to the
Faculty of the Graduate School of the
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This project for the Master of Science degree by

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and

Gary Michael Hallowell

has been approved for the

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Harvey M. Gates

S. W. Maley

Floyd K. Becker

Date November 25, 1986

Livie, Brian Keith (M.S., Telecommunications)
Hallowell, Gary Michael (M.S., Telecommunications)
Selection of Packet Switched Facilities for the Search and Rescue Communications Network Based on Performance.
Thesis directed by Doctor of Philosophy Harvey M. Gates

Since late 1982, a new satellite system has enabled search and rescue forces to locate, within hours and with relative pin-point accuracy, ships and aircraft in distress. Known as SARSAT, this system combines the research efforts of several nations including the United States, Canada, France, and the Soviet Union.

During the demonstration and evaluation of this system, studies showed problems with the communications network, including long delays, loss of data, lengthy downtime, and slow network service. The hub of the United States SARSAT network, the United States Mission Control Center, is being moved from the Air Force to the National Oceanic and Atmospheric Administration. It has been decided that this transition provides an opportune time to consider ways and means of improving the SARSAT network.

The purpose of this study is to look at the performance of alternative packet-switched data network strategies and make recommendations for a future SARSAT communications network.

In addition, this study highlights some of the difficulties facing the telecommunications analyst when evaluating alternative systems. These include a reluctance by networks to provide detailed performance data and a lack of industry standardization in specification of this information.

Networks were selected that represented the different implementation strategies. Performance data was requested and received from each network. This data was then compared and the performance specifications were analyzed with regards to the American National Standard X3.102 parameters. Then, each network was evaluated with respect to the SARNET requirements. Finally, conclusions and recommendations were made.

ACKNOWLEDGMENTS

To Dr. Harvey Gates, for providing us with the concept as well as the guidance for this project.

To Professor Floyd Becker and Professor S. W. Maley, our committee members, for their assistance and comments on this document.

To David Wortendyke and A. Glenn Hanson, employees of the Institute for Telecommunication Sciences (ITS), National Telecommunications and Information Administration (NTIA), U. S. Department of Commerce, for their knowledge and insight into ANS X3.102.

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Finally, to all of the members of BDM, our most sincere thanks and deepest gratitude for providing administrative support in the preparation of this document.

DEDICATION

This study is dedicated to our devoted and supportive families, especially our wives, Roberta and Leigh Ann. Without their patience and understanding, this project would not have been completed.

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INTRODUCTION

Background

Since September of 1982, survivors of aircraft and maritime disasters have been aided by a revolutionary new satellite system that has enabled search and rescue forces to locate, within hours and with relative pin-point accuracy, ships and aircraft in distress.

The COSPAS/SARSAT System

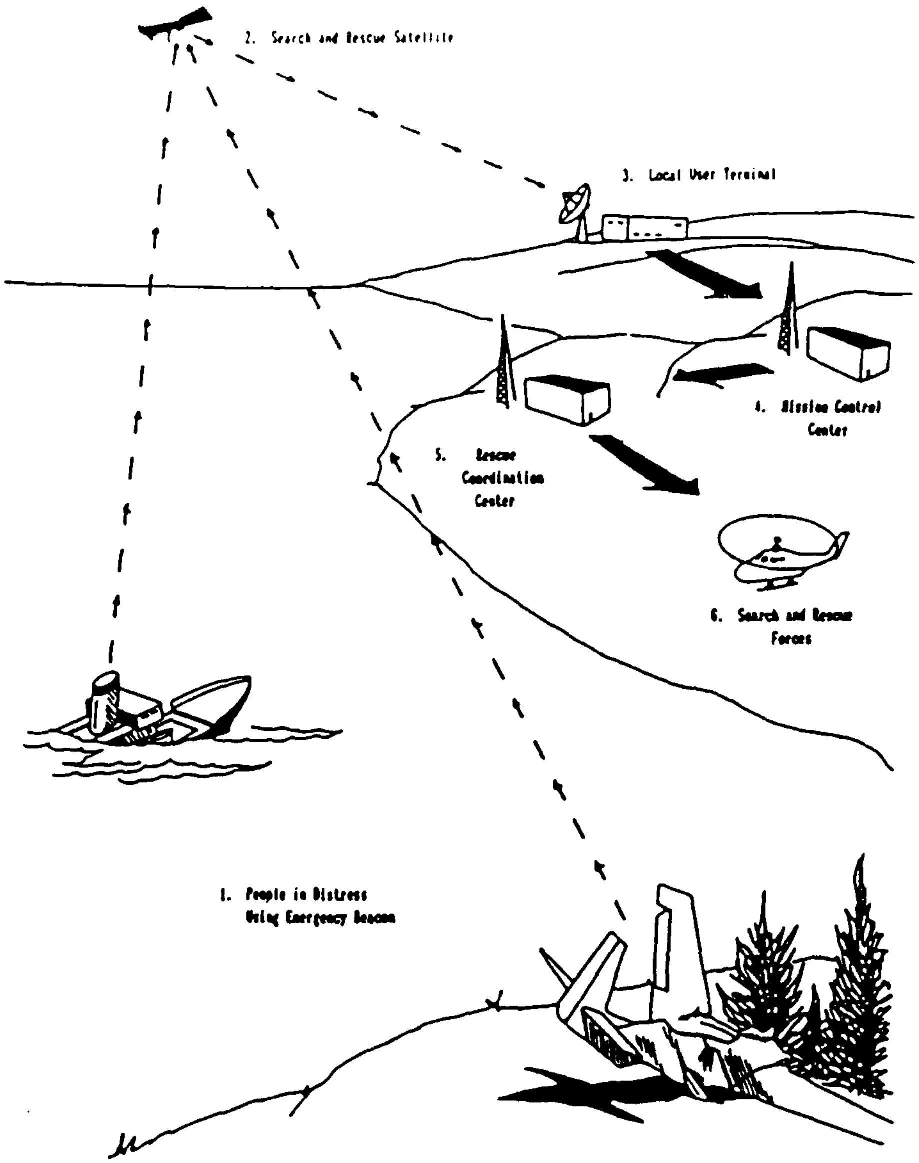
This system, known as COSPAS/SARSAT (Space System for Search of Vessels in Distress / Search and Rescue Satellite Aided Tracking), combines the research efforts of several nations which began independent development of the idea in the early 1970's. Canada's Department of Communication (DOC), France's Centre National D'Etudes Spatiales (CNES), the United States' National Aeronautics and Space Administration (NASA), and the Soviet Union's Ministry of Merchant Marine (MORFLOT) make up the present partners in this joint venture of satellite-aided search and rescue.

Using satellites listening to the international emergency frequencies, distress signals from emergency

beacons are relayed to earth stations located around the globe (see figure 1-1). These earth stations, known as Local User Terminals (LUTs), digitally process these signals to determine their origination. The Doppler shift, caused by the movement of the satellite relative to the location of the emergency beacon, is used in determining the beacon's location. Then the alert and its location are passed on to an appropriate Rescue Coordination Center (RCC) or to another nation by a national Mission Control Center (MCC).

Each of the participating COSPAS/SARSAT nations has its own MCC which serves to coordinate the activities of the LUTs and RCCs belonging to that nation. The United States Mission Control Center (USMCC) is presently operated by the United States Air Force (USAF) and acts as operational point-of-contact between the United States and other nations for the exchange of distress and other operational data.

The Rescue Coordination Center has responsibility for actual search and rescue (SAR) operations. Within the United States, the United States Coast Guard (USCG) is responsible for all maritime Search And Rescue operations and operates RCCs along the nation's coastal regions and waterways. The USAF operates two other RCCs responsible for coordination of inland SAR activities.



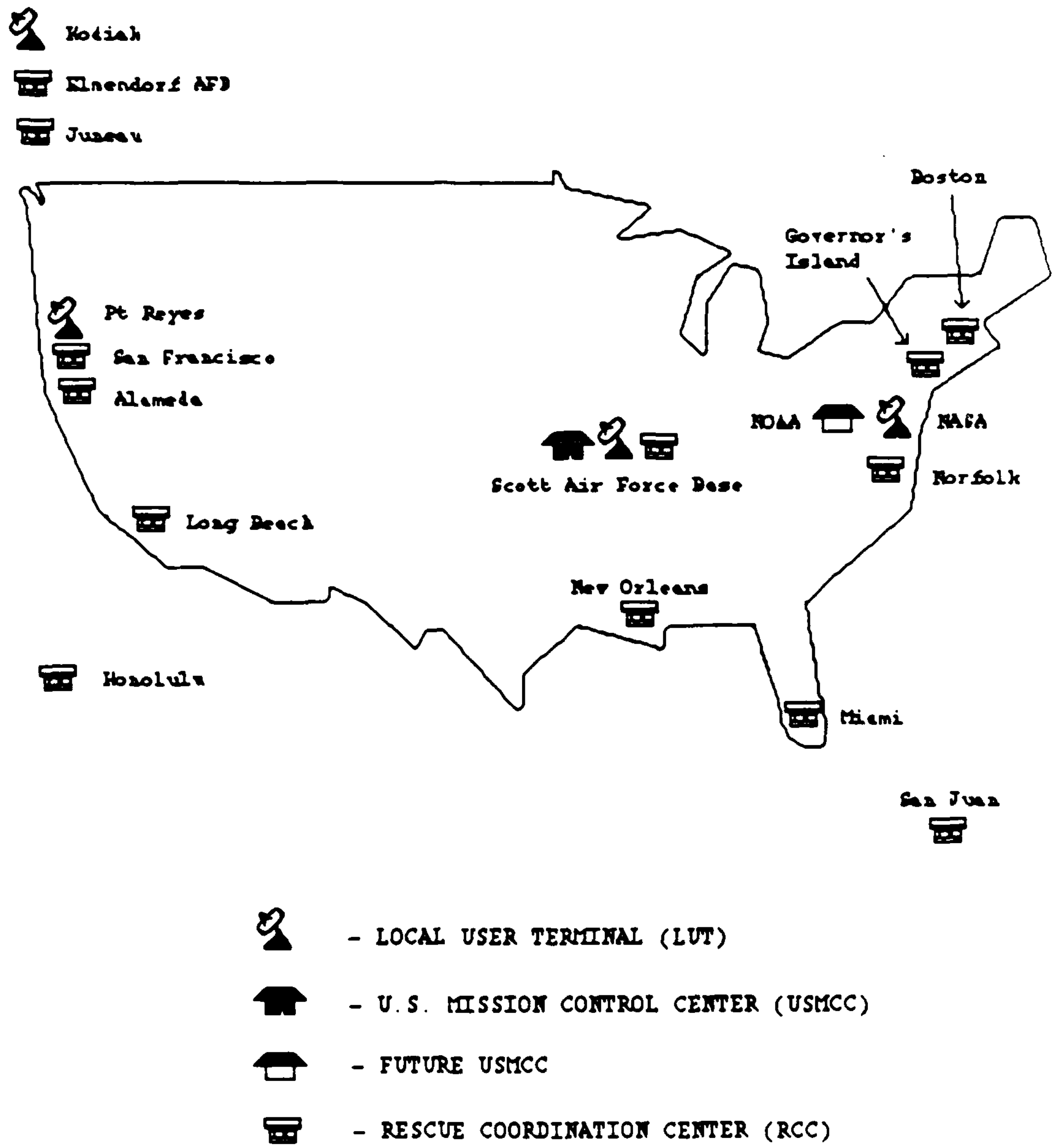
The SARSAT System
Figure 1-1.

The COSPAS/SARSAT communications network consists of each nation's Mission Control Center and its network of Local User Terminals and Rescue Coordination Centers. The locations of the United States Mission Control Center and its network of LUTs and RCCs are shown in figure 1-2. Presently, interconnection between the USMCC, Canadian Mission Control Center (CMCC) and the American RCCs is being handled with the military's AUTODIN (Automatic Digital Network) system. Communication between the USMCC, French Mission Control Center (FMCC) and the Soviet Union is done over Telex facilities.

Problems With The Current Network

During demonstration and evaluation (D&E) of the SARSAT system, studies showed deficiencies with the present communications network. These included: high in-route transit times and loss of message traffic through the AUTODIN; lengthy downtime of dedicated lines largely due to the lack of automatic network monitoring; and slow response times in the servicing of line problems.[1]

Although the time to detect an emergency situation has been greatly reduced, the D&E studies show clearly that important life-saving information was often facing unacceptable delays through the AUTODIN system. Figure 1-3 shows the distribution of transmission delays



SARSAT Network in the United States
Figure 1-2.

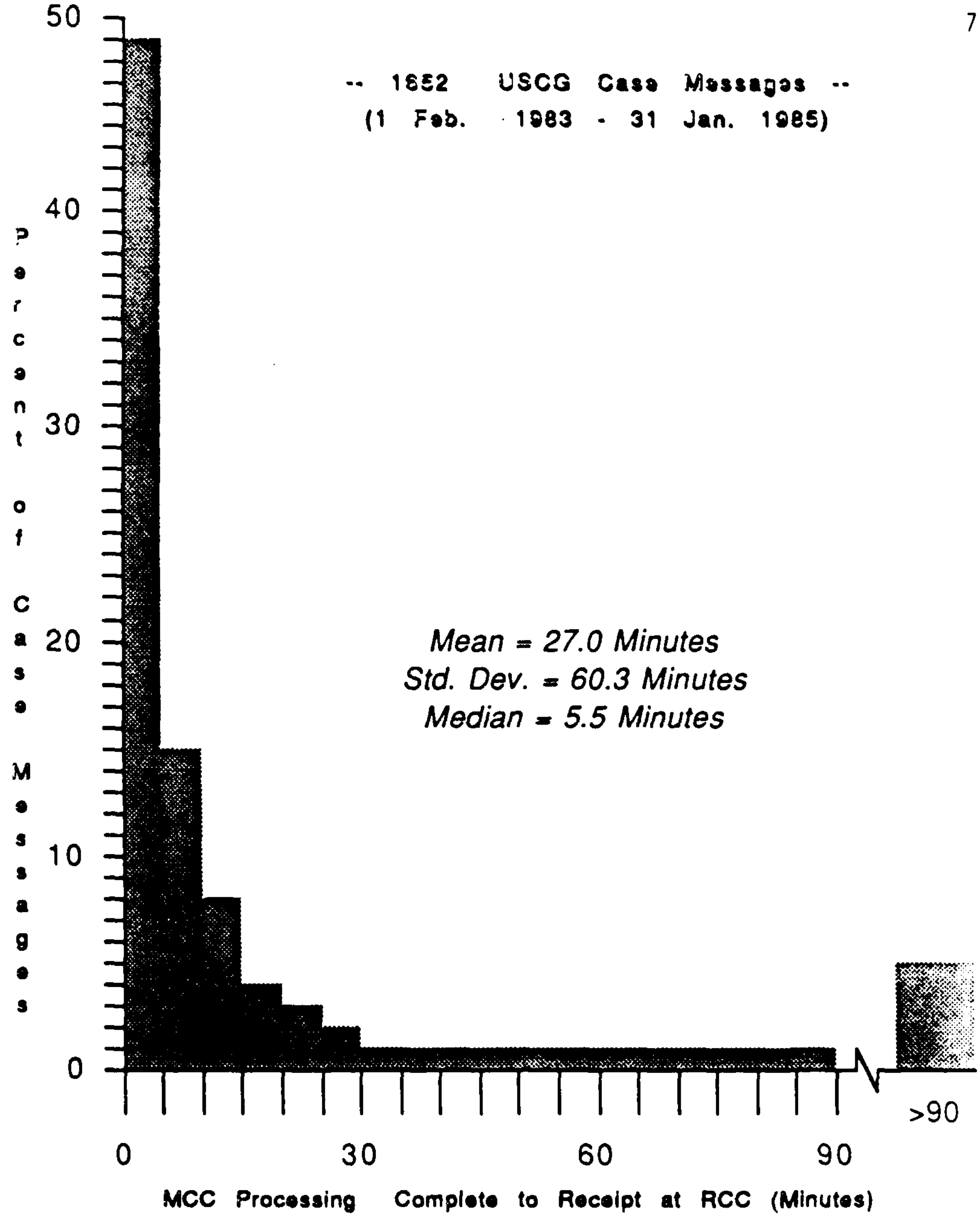
of SARSAT traffic traveling through the AUTODIN system during this period.[2]

The importance of swift response to a disaster is illustrated by studies showing that only 20 percent of injured aircraft crash victims survive past the first 24 hours and only 50 percent of uninjured crash victims survive beyond 72 hours.[3] In other studies, it has been shown that if help reaches victims in 8 hours or less, their odds of survival are over 50 percent. But, the odds of survival fall below 10 percent if help is delayed beyond 48 hours.[4]

To further compound these problems, it is expected that before the end of this decade, the SARSAT system will expand and grow to include countries from South America and possibly the Caribbean and Hawaiian areas. This growth will mean a proportional increase in the cost of communication facilities. And, unless standardization of communication protocols is established, there will likely be problems interfacing these new participants to the COSPAS/SARSAT system.

Move Of The USMCC To NOAA

To provide enhanced MCC capabilities and to prepare the United States for its responsibilities in a fully operational COSPAS/SARSAT system, the decision was made in 1984 to transfer USMCC operations from the USAF



Distribution of Transmission Delays
Figure 1-3.

From: Figure 6-9 of the Coast Guard Final Evaluation Report, attached to a letter from John Bellantoni, U. S. Department of Transportation, to A. Booth, U. S. Department of Commerce, May 7, 1986.

to the National Oceanic and Atmospheric Administration (NOAA).[5] The NOAA agency responsible for operation of the USMCC will be the National Environmental Satellite, Data and Information Service (NESDIS), located at Suitland, Maryland.

Implementation of the AUTODIN portion of the network by NOAA has several drawbacks. These include: a long lead time required to obtain use of AUTODIN through the Defense Communications Agency (DCA); extensive and expensive qualification testing; and conversion to a totally classified system requiring extensive security provisions.

It has been decided that transition of USMCC responsibilities from the USAF to NOAA provides an opportune time to consider ways and means of improving the SARSAT communications network.

The SARNET Solution

Over the past few years, the development of packet-switched data networks (PSDNs) has offered a solution to the rising cost of communications facilities. Studies show that users of dedicated communication lines typically use these facilities far below their capacity whereas the PSDNs allow many users to utilize the same facilities much more efficiently. While it is generally agreed that a PSDN is operationally a less expensive

means of communication, a study of alternatives for the SARSAT network concluded that such a network would cost about the same or slightly less than dedicated facilities with the same data rates.[6] Even so, PSDNs offer many advantages that the SARSAT community finds important.

These advantages include: (1) responsibility by the vendor for end-to-end performance of the network; (2) adherence to the International Telephone and Telegraph Consultative Committee (CCITT) recommendations for procedures and standards by packet-switched data networks; (3) service to all major cities in the United States and gateways to many other countries; (4) cost based on speed of service and amount of data rather than distance; (5) error detection and correction techniques to ensure almost error-free transmission of data; and (6) the dynamic routing of data, avoiding the reliance on intermediate MCCs to pass along information.[7]

The SARNET pilot program will provide for demonstration and evaluation of PSDN services in support of the SARSAT network. The stated purpose of the demonstration and evaluation is to estimate the advantage to be achieved in the areas of: (1) improved message delivery times; (2) improved reliability; (3) improved failure detection and reconfiguration capability; (4) potential cost reduction and (5) improved international communications.[8]

To implement a network solution prior to the move of the USMCC to NOAA, the demonstration and evaluation of PSDN services must begin as soon as possible. The United States Coast Guard already uses the services of GTE Telenet and can quickly expand this arrangement to include the other test sites in the pilot program. For these reasons, GTE Telenet was selected as the PSDN for the pilot SARNET system.

Purpose of the Study

The purpose of this study is to look at alternative packet-switched data network strategies with the intent of recommending a suitable application for the SARNET system.

Methodology

Networks were selected that represented the different implementation strategies. Performance data was requested and received from each network. This data was then compared. Next, the performance specifications were analyzed with regards to the American National Standard X3.102 parameters. Finally, each network was evaluated with respect to the SARNET requirements.

Expected Results

Besides the obvious objective of recommending a PSDN strategy that best suits the requirements of the SARNET system, this study will highlight the difficulties facing the telecommunications analyst when confronted with the task of evaluating and selecting appropriate facilities. These difficulties include the networks reluctance to provide detailed performance data and inconsistencies in performance criteria. Finally, the study will spotlight the American National Standard (ANS) X3.102 (which defines user-oriented, system-independent data communication performance parameters) and discuss the compliance with this standard by packet-switched network vendors.

Scope of the Study

It is the desire of the authors to produce a study that would be of some benefit to the United States Air Force as well as add to the field of study in telecommunications. The SARSAT project has been an area of interest to both authors and the SARNET application provides a wide range of topics from which to choose. With such a large selection of topics, several limitations regarding the scope of the study had to be made. A summary of those limitations follows.

Alternatives Considered

A review of alternative public PSDNs would be redundant, having been accomplished many times before by graduate students, industry analysts and the government.

Instead, it was decided to compare representative PSDNs from both the military and public areas. Within the public PSDNs, a further distinction was made between the terrestrial and satellite based systems.

The first category considered is the military PSDN. The only true military packet-switched data network is the Defense Data Network (DDN). Designed specifically to support the military requirements of precedence, preemption, security and survivability, the DDN was selected because it is the heir apparent to the AUTODIN system which now supports the SARSAT project.

The next category is the commercial land based PSDN. As the oldest and largest public packet-switched data network, GTE Telenet was selected because it is fairly representative of the PSDNs in this category.

The final category considered is the commercial space based PSDN. This is a relatively new entry into packet-switching arena and is best represented by the Equatorial Communications Corporation.

Criteria Considered

As with private industry, government agencies will publish a request for proposal (RFP) when they require procurement of equipment or services. In an effort to ensure that fair practices are followed in the awarding of government contracts, the technical evaluation of proposals is considered prior to, and separate from, the cost analysis. Attempting to follow this practice as well as to restrict the scope of this project, the comparison of alternatives has been limited to a discussion of technical merit only.

Further, since it was not feasible to produce an actual RFP for vendors to respond to, evaluation of technical specifications was limited to those which were provided by either the vendor through product literature and/or personal interviews or by publications such as the Datapro or Auerbach series on data communications. Proprietary information was not requested nor received for the purpose of this study.

SARNET Application

As mentioned above, the SARNET is an attempt to demonstrate and evaluate the effectiveness of a PSDN in support of the SARSAT system. While the test SARNET system will include network nodes in only five locations,

consideration will be given to the future configuration of an international SARNET.

The performance requirements for the SARNET were taken from a Statement of Work (SOW) drafted by NOAA for the procurement of network services from GTE Telenet. This SOW was never used since it was decided to procure these services through an existing contract with the United States Coast Guard. Keeping in mind that these requirements will slant the analysis towards recommendation of GTE Telenet, their use is still considered valid since they all fall within reasonable expectations of a packet-switched data network. In any case, this Statement Of Work provides an excellent example of the type of specifications a user will provide to a vendor.

In addition to these requirements, there are also several non-performance as well as non-technical criteria that are considered. These include service, maintenance and security.

Organization of the Study

This chapter has provided an overview of the SARSAT system and its communications network. It has covered the problems that have been documented during the SARSAT demonstration and evaluation, discussed the

present network's shortcomings and proposed SARNET solution, and outlined the goals of this study.

Chapter two provides an analysis of three different implementations of PSDNs: the military packet switched network, the terrestrial public PSDN and the satellite based PSDN. First, the specific performance specifications of each network are discussed, followed by a comparison of each network. In closing, ANS X3.102 is introduced and a discussion on compliance and its relevance is presented.

Chapter three attempts to map the requirements of the SARNET application to the different PSDN strategies. First the specific SARNET requirements are discussed and then there is an evaluation of each PSDN's ability to meet these specifications.

Chapter four presents the authors' conclusions and recommendations resulting from this study. These include observations concerning the technical evaluation of data network performance, the need for better compliance with ANS X3.102 and the selection of a PSDN for the SARNET application. Finally, recommendations are made based upon these conclusions.

NOTES

1. Office of Satellite Data Processing and Distribution, Information Processing Division, National Environmental Satellite, Data, and Information Service, National Oceanic and Atmospheric Administration, Pilot Program Plan for the SARSAT Search and Rescue Communications Network (SARNET), draft, (Washington D. C.), February, 1986, p. 2-1.

2. From figure 6-9 of the Coast Guard Final Evaluation Report, attached to a letter from John Bellantoni, U. S. Department of Transportation, to A. Booth, U. S. Department of Commerce, May 7, 1986

3. Office of Public Affairs, Military Airlift Command, U. S. Air Force, Search and Rescue Satellite-Aided Tracking Program (SARSAT), fact sheet, (Scott Air Force Base), February 1985.

4. F. Flatow and B. Trudell, "SARSAT - Using Space for the Search and Rescue of Lives in Distress", AIAA 10th Communication Satellite Systems Conference, (New York, New York), March 19-22, 1984, p. 459.

5. Office of Satellite Data Processing and Distribution, Information Processing Division, National Environmental Satellite, Data, and Information Service, National Oceanic and Atmospheric Administration, draft Statement of Work for procurement of GTE Telenet packet-switched data network services for NOAA, (Washington D. C.), 1986, NOTE: This Statement of Work was not used due to a decision to have the United States Coast Guard procure these services through existing contracts.

6. Wendell Clouse, National Oceanic and Atmospheric Administration, in a presentation paper on SARSAT Communications to the SARSAT Interagency Joint Working Group, November 20-21, referenced by National Oceanic and Atmospheric Administration in draft Pilot Program Plan for the SARSAT Search and Rescue Communications Network (SARNET), (Washington D. C.), February, 1986, p. 3-1.

7. Pilot Program Plan for the SARSAT Search and Rescue Communications Network (SARNET), p. 3-2.

8. Ibid., p. 4-1.

CHAPTER II

PERFORMANCE ANALYSIS

This chapter analyzes the network performance specifications of the Defense Data Network, the GTE Telenet, and the Equatorial Communications Company. To start with, the performance data provided by each network is summarized. Then these specifications are correlated; first among the three networks, and then with the performance parameters of ANS X3.102.

Network Performance Data

Obtained through network literature, interviews and other independent publications, the following is a summary of the performance data for the DDN, Telenet, and Equatorial packet-switched data networks.

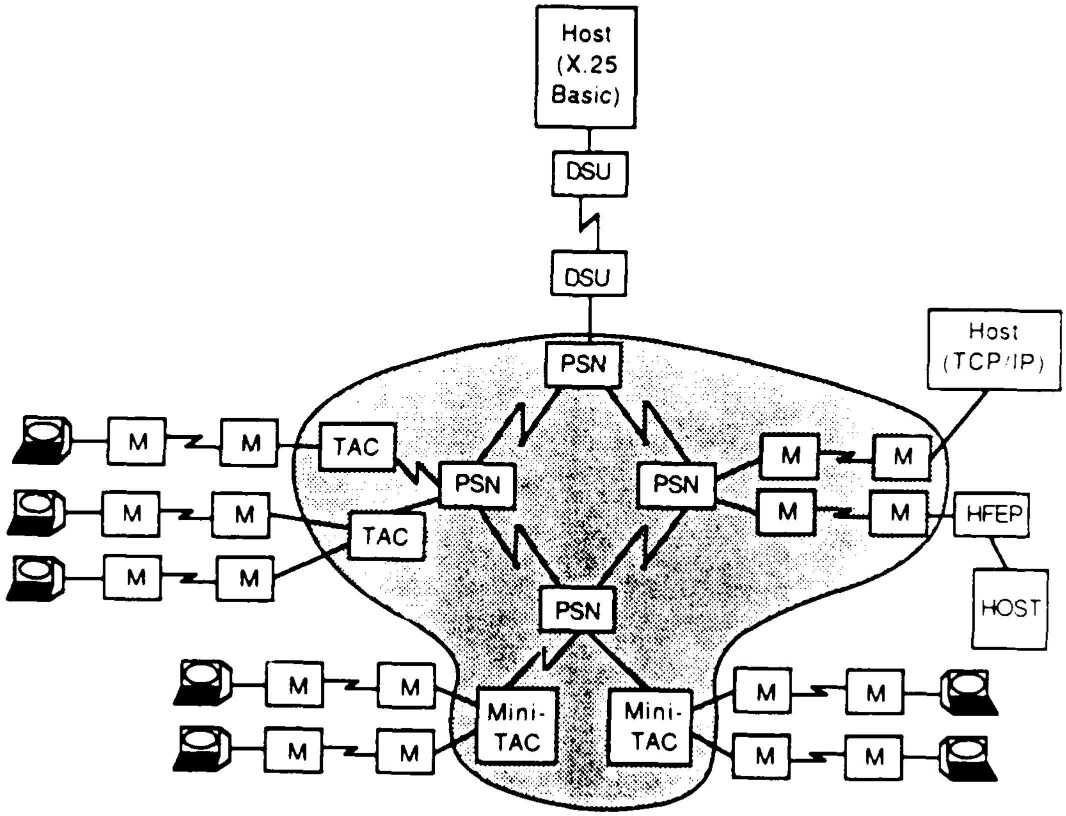
Defense Data Network

Established in early 1982 by the Secretary of Defense, the Defense Data Network (DDN) is a packet switched network designed to support the long haul data traffic of the military services and defense agencies. By the end of 1986, the DDN will be made up of about 174 switching nodes interconnected by 300 leased circuits and

satellite backbone links located throughout the Continental United States (CONUS) and overseas. Based on technology developed by the Defense Advanced Research Projects Agency (DARPA) in a 1969 research and development program, the DDN is designed to handle the military's requirements of survivability, precedence and preemption. In addition, the DDN provides for high performance and interoperability with diverse computer systems and terminals and achieves cost savings through the combining of communications requirements of many users over a common backbone.[1] Figure 2-1 illustrates the various methods of accessing the network. The DDN performance characteristics, provided by the Defense Communications Agency (DCA), follow.

Data Rates. The network can be broken up into two functional areas: (1) the backbone network, which includes the trunk circuits and packet switches; and (2) the access network, which includes the circuits and equipment that enable subscriber systems to connect to the backbone.

The data transmission rates of a DDN trunk circuit range from 2400 bits per second (bps) over a voice grade line to 56,000 bps using a Dataphone Digital Service (DDS) line.[2] If DDS is not available, then the maximum line speed available over analog DDN trunks is 50,000 bps.[3] Most of the backbone transmission links



M = Modem
DSU = Data Service Unit
HFEP = Host Front End Processor
PSN = Packet Switching Node
TAC = Terminal Acess Controller

Defense Data Network Configuration
Figure 2-1.

From: Network Strategies Inc., The DDN Course, prepared for the Defense Data Network Program Management Office, Deffense Communications Agency, U. S. Department of Defense, Fairfax, Virginia, 1986.

have typical data rates of 56,000 bps[4]; however, in Europe, 9,600 bps circuits are employed.[5] Transmission speeds of host access circuits are from 4,800 to 56,000 bits per second.[6] Terminals are connected to Terminal Access Controllers (TACs) or mini-TACs with either direct lines operating at speeds from 75 to 9,600 bps[7] or dial-up lines from 100 to 2,400 bps[8]. Each TAC is connected to a packet switch in the network backbone via a direct line operating from 9,600 to 56,000 bps.[9]

Delay. Average end-to-end delay for transmission of high priority packets across the DDN backbone is about 90 milliseconds, with 99 percent of all packets being transmitted within approximately one-half second. Using transoceanic satellite circuits increases these figures by 300 milliseconds (See Table 2-1).[10]

	Precedence	Domestic	Overseas
Average	High	0.09 sec	0.39 sec
	Low	0.122 sec	0.422 sec
99th Percentile	High	0.224 sec	0.524 sec
	Low	0.458 sec	0.758 sec

Backbone Network Delay for the DDN
Table 2-1.

FROM: Network Strategies, Inc., The DDN Course, prepared for the Defense Data Network Program Management Office, Defense Communications Agency, U. S. Department of Defense, April, 1986.

Response Time. Response time of interactive systems connected to the DDN is about 200 milliseconds

more than the response time of interactive systems with dedicated long-haul circuits.[11]

Accuracy. The expected undetected error rate is 4.2×10^{-18} or less using the Transmission Control Protocol/Internet Protocol (TCP/IP).[12] "This means that if a user were to send a full TCP Packet (8,063 bits) every second of every hour of every day, a bit error would slip through the network undetected only once every million years."[13] All detected errors result in automatic retransmission of the packet in error.[14]

Reliability. The probability of accidental misdelivery of a data unit is less than 5.5×10^{-12} or one packet in 181 billion.[15]

Availability. Designed to provide continuous operation 24 hours per day, 7 days per week, the DDN can provide an availability of at least 99 percent between any pair of single-homed users (users with single access links to the network). This comprises all network components between the source and destination host or terminal. Subscribers may enhance their network availability by using two access links (dual-homed), each attached to a different switching node. Dual-homed subscribers will have a network availability of at least 99.95 percent.[16]

DATA RATES	
Backbone Network	
Voice Grade Trunks	2400 bps
Dataphone Digital Service	56,000 bps
Analog Trunks	50,000 bps
Access Network	
Host Access Circuits	4800-56,000 bps
Terminal Access Controllers	9600-56,000 bps
Terminal to TAC	
Dedicated Lines	75-9600 bps
Dial-up Lines	100-2400 bps
DELAYS	
Domestic	
High Precedence	90 ms
Low Precedence	122 ms
Overseas	
High Precedence	390 ms
Low Precedence	422 ms
RESPONSE TIME	200 ms greater than interactive dedicated long haul circuits
ACCURACY	4.2×10^{-18}
RELIABILITY	5.5×10^{-12}
AVAILABILITY	
Single Homed Users	99.00%
Dual Homed Users	99.95%

Summary of DDN Performance Data
Table 2-2.

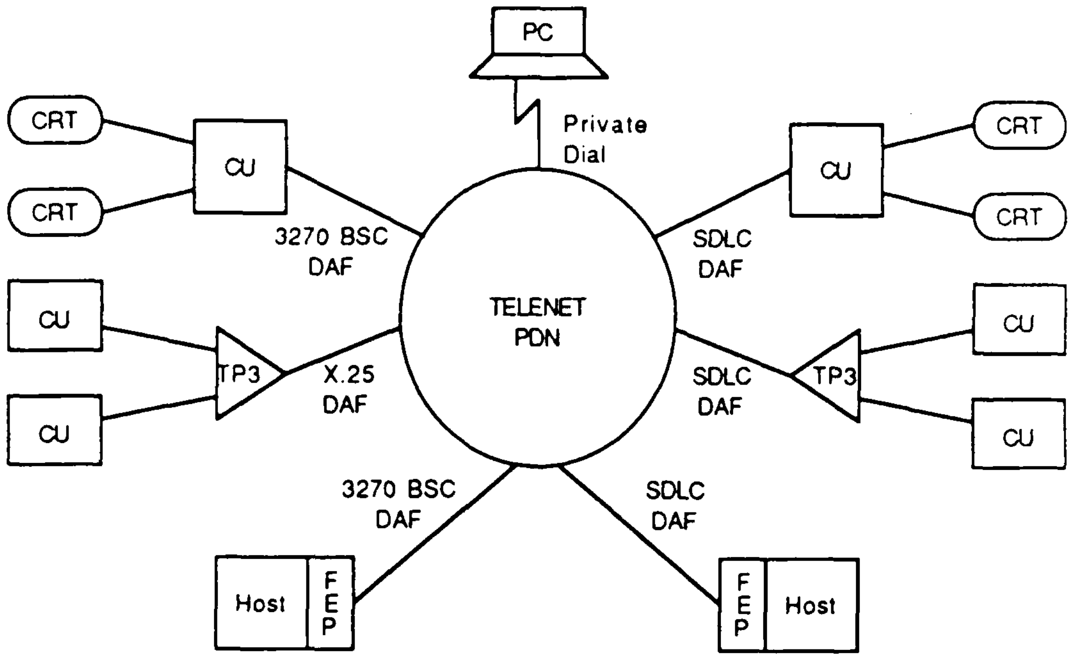
GTE Telenet

In 1975 the Telenet Public Data Network (PDN) was established as the first public network utilizing packet switching. Today it offers adaptive, flexible data communications service to over 17,000 exchanges located in the United States. Worldwide connectivity is available in almost 70 countries making Telenet the largest packet switching network of its kind.[17] Figure 2-2 shows Telenet's basic network configuration.

Performance characteristics of the network were obtained from an interview with a Telenet salesman and Systems Engineer and through company and other literature. Below is a compilation of the performance characteristics provided and acquired.

Data Rates. The Telenet PDN consists of several switching nodes that are primarily interconnected by 56,000 bps digital links. The remainder are connected using T-1 carrier service. International gateways normally allow 9600 bps speeds but some, like Canada's, permit 56,000 bps.[18] Access to the switching nodes is available on circuits operating at speeds up to 14,400 bits per second.[19]

To access the Telenet PDN a user can utilize either dedicated or dial-up lines. If dedicated lines are used, the customer's host computer is connected to a



PC - Personal Computer
CRT - Cathode Ray Tube
CU - Control Unit
DAF- Dedicated Access Facility
TP3 - Telenet Processor
FEP - Front End Processor

GTE Telenet Configuration
Figure 2-2.

From: GTE Telenet Communications Corporation, <u>3270 BSC Service</u>, and <u>SDLC Service</u>, Reston, Virginia, 1985.

Dedicated Access Facility (DAF) located at a Telenet Central Office (TCO).[20] If a hardware interface is required, Telenet offers connection by way of the Telenet Processor (TP) 3000 or TP 4000.[21]

The TP 3000 allows synchronous terminal speeds of 2400 to 56,000 bps and asynchronous terminal speeds between 50 and 9600 bps. With the TP 3000, the maximum DAF operating speed is 19,200 bps.[22]

Using the TP 4000 allows synchronous terminals to operate between 2400 and 56,000 bps and asynchronous terminals and host computers to operate at speeds from 75 to 9600 bps. Operating speeds of a DAF with a TP 4000 connected is between 2400 and 14,400 bps.[23]

Dial-up connections to the PDN allow terminal transmission speeds from 110 to 1800 bps. Table 2-3 shows a breakdown of transmission speeds in relation to Telenet ports.[24]

<u>Delay</u>. Datapro states that Telenet's "average delivery delay through the network is about 0.2 second, excluding transit time across customer network access lines."[25]

<u>Response Time</u>. Telenet publishes an average response time for a complete end-to-end loop of 300 to 500 milliseconds for their dial services.[26] Telenet personnel quoted average call set-up delays of around 400

Transmission Speed (bps)	TCO ACCESS PORTS			PRIVATE PACKET EXCHANGE
	Public Dial-In Ports	Private Dial Ports		Dial-In
		Dial-In	Dial-Out	
110		X	X	X
134.5		X	X	X
150		X	X	X
300		X	X	X
110-300 ASP	X	X		X
1200	X	X		X
1800				X

Summary of Transmission Speeds for
Asynchronous Telenet Ports
Table 2-3.

From: Datapro Research Corporation, "GTE Telenet Communications Packet-Switched Data Services", Switched and Nonswitched Transmission Facilities, McGraw-Hill, 1985.

milliseconds and coast-to-coast call set-up delay averages of 420 milliseconds. These response times are measured from the carriage return at the terminal to the reception of the first byte back to the same terminal.[27]

Error Detection Effectiveness. Because of the statistical/error test applied in the X.25 protocol, Telenet advertises "a nearly error free data communications service." This equates to "a transmission environment of approximately one bit error for every 10^{12} bits sent."[28]

Reliability. Telenet literature refers to reliability in terms of how their network is configured. Because the high-speed circuits of the backbone are connected by a series of switching nodes that do the interpreting and routing of data between themselves and other nodes, and operate independently of each other, a failure on Telenet's network-side is virtually impossible. This assures "the highest possible reliability to the user."[29] Also, Telenet's 56,000 bps trunks are only allowed to carry 50% of their maximum possible traffic load. This makes it possible to transfer the entire load of one trunk to another without data loss should one trunk become inoperable.[30] To insure this reliability, Telenet provides 24-hour, 7-day

DATA RATES	
Backbone Network	
Primary	56,000 bps
Secondary	T-1 Carrier
Gateways	9600 or 56,000 bps
Access to Backbone	14,400 bps
Access Network	
Dedicated Synchronous	2400-56,000 bps
Dedicated Asynchronous	50-9600 bps
Dial-up Asynchronous	110-1800 bps
RESPONSE TIME	300-500 ms
Average Call Set-up	400 ms
Coast-to-Coast Call Set-up	420 ms
DELAY	
Average	0.2 second
ERROR DETECTION EFFECTIVENESS	1×10^{-12}
AVAILABILITY	
Network	99.9%
Switch	99.995%
Dial-up Grade of Service	P.01

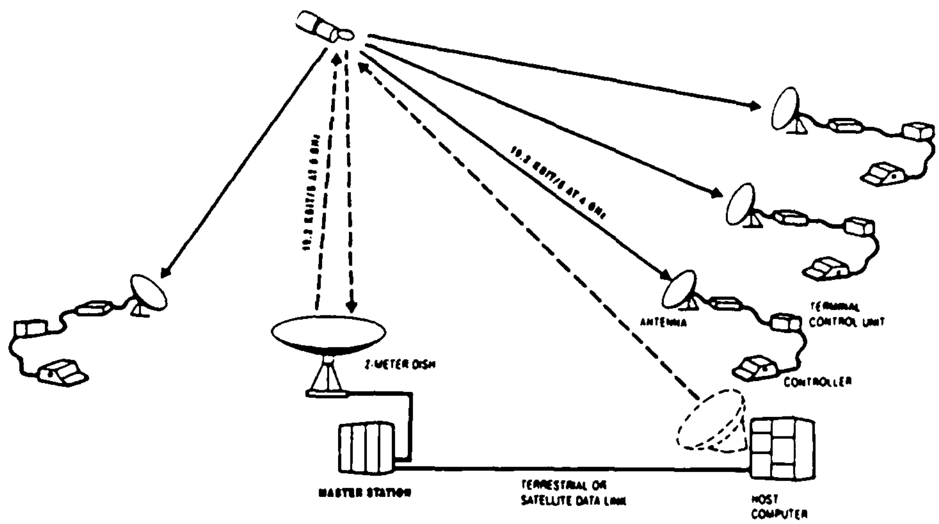
Summary of Telenet Performance Data
Table 2-4.

a week customer service and network management functions.[31]

Availability. Telenet states that their Public Data Network offers a 99.9% availability[32] while their switch availability is around 99.995%.[33] Local access availability for terminals using public dial-in ports is kept at a grade of service of P.01. "This means that there is only a 1.0% chance of a busy port during peak hour when a user dials the Telenet network."[34]

Equatorial Communications Company

Equatorial Communications Company is a satellite based corporation that offers low speed packet-switched data communications to large corporate customers. Incorporated in December 1979, Equatorial uses low-powered dishes, spread spectrum technology, and geostationary satellites orbiting over the equator to provide data communications networking.[35] Equatorial's general network configuration is shown in Figure 2-3. With over one hundred customers[36] and 20,000 micro earth stations installed to date,[37] Equatorial operates the "largest commercial satellite-based private data communications network in the world."[38] Equatorial has plans underway to increase future networking capacity by building its own satellite to be launched from the space shuttle and thereby increase its international marketing



Equatorial Network Configuration
Figure 2-3.

From: Philip L. Arst and Willie Ivey, "Hybrid satellite networks for distributed data applications", Data Communications, reprint, McGraw-Hill, March, 1985.

capability.[39] Equatorial's performance specifications follow.

Data Rates. Equatorial offers network transmission capacity from 150 to 19,200 bits per second depending on the type of service required and the micro earth stations used.[40] Services offered include point-to-multipoint data distribution networking and interactive data communications networking.[41]

In Equatorial's point-to-multipoint networking, the data source transmits its information by way of satellite or terrestrial links to one of the 11 meter master earth stations located in Mountain View, California. From there, the information is packetized and transmitted using spread spectrum technology to Equatorial transponders on geostationary satellites. The satellites then relay the data to multiple receive-only micro earth stations located around the country. These small diameter micro earth stations are manufactured by Equatorial and designated as the C-100 and C-120 series dishes.[42]

The C-100 micro earth stations advertise data rates of 15 to 2400 characters per second[43] while the C-120 series dishes give data rates from 45 to 19,200 bits per second.[44] Both the C-100 and the C-120 series micro earth stations support I/O (input/output) mode interfaces as shown in Table 2-5.[45]

Data Rate (bps)	C-100 and C-120 Micro Earth Station I/O Mode Interfaces			C-200 Micro Earth Station	
	Serial Async.	Serial Async. or Sync.	Intelligent Programmable	Async.	Sync.
45	x				
56.9				x	
75	x				
135	x				
150	x				
225	x				
300	x	x	x	x	
600	x	x	x	x	
1,200	x	x	x	x	
2,400	x	x	x	x	x
4,800	x	x	x	x	x
9,600	x	x	x	x	x
19,200		x	x	x	x

Summary of Equatorial Data Rates
Table 2-5.

From: Equatorial Communications Company, C-100 Series Micro Earth Stations for Satellite Data Distribution, C-120 Series Micro Earth Station for Satellite Data Distribution, and C-200 Series Micro Earth Stations for the Equastar Satellite Trnasaction Network, Mountain View, California.

For interactive data communications networking, Equatorial uses the C-200 series transmit/receive micro earth stations. Although the master earth station is transmitting data at a maximum of 153,600 bps on each channel, and the C-200 micro earth stations are receiving at that rate, they can only process data at a rate of 19,200 bps. Maximum transmit capability of the C-200 series dishes is 1200 or 9600 bps.[46] Interface data rates to the C-200 series micro earth stations are also shown in Table 2-5.[47]

Delay. Because Equatorial uses satellites to relay its data from one station to another, the propagation time experienced when data travels from a transmitter to the satellite and back to the receiving earth station is quite high. Equatorial states that its propagation delay is a relatively constant time of 250 milliseconds and regards it as advantageous because it does remain about the same all the time and does not vary like land-line network delays do.[48] Delays due to processing the data on either end of the satellite link are negligible in comparison to the propagation delay and are therefore considered to be of no consequence.[49]

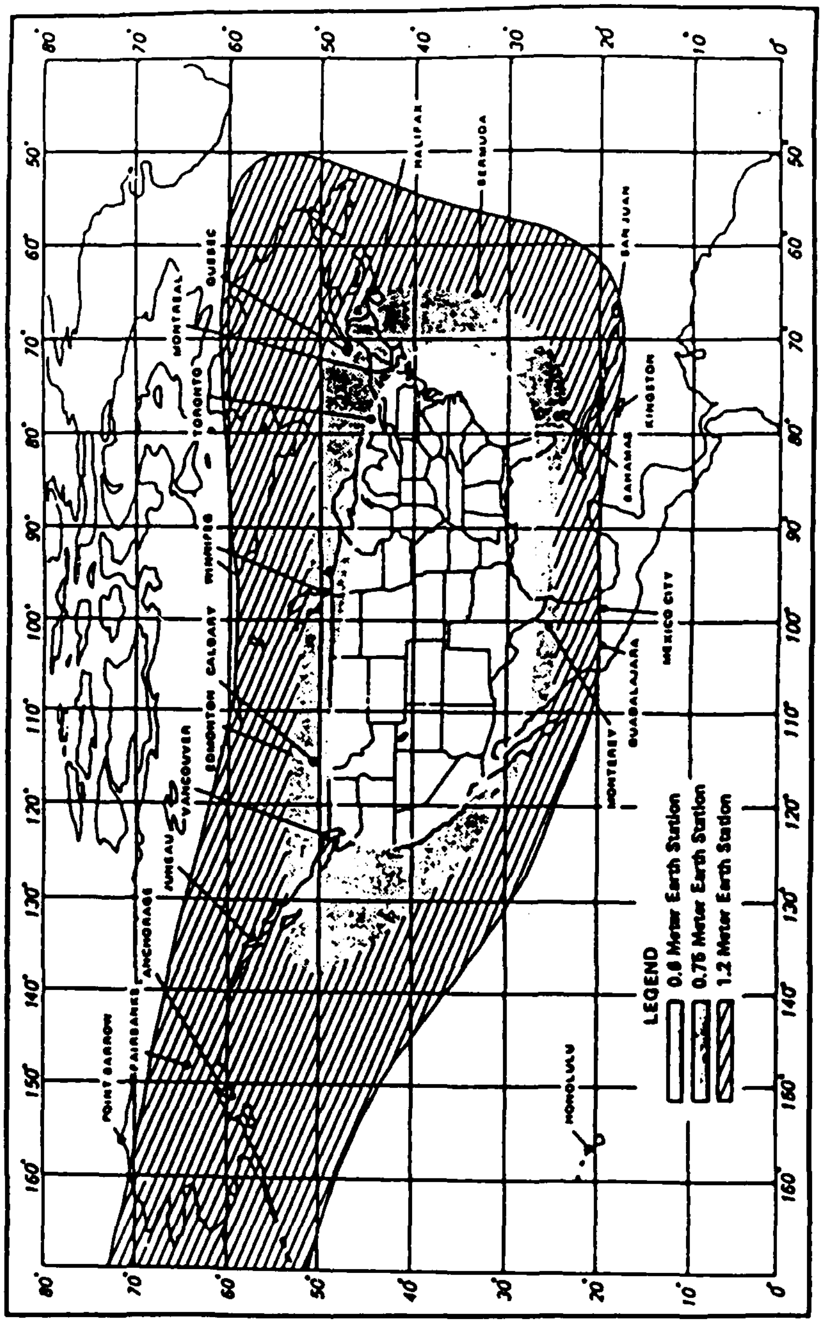
Bit Error Rate. Using the C-100 and C-120 series receive only micro earth stations, Equatorial's bit error rate is no worse than 10^{-7}, which equates to "better than

one in 10 million."[50] Using the C-200 transmit/receive earth stations the bit error rate is still 10^{-7}; however, this can be improved to 10^{-12} or "1 in a trillion" with automatic retransmission incorrect of messages after bit error detection.[51]

Figure 2-4 shows the boundaries within which the Equatorial earth stations will operate with a bit error rate of 1×10^{-5} or better (with a nominal margin of 3 dB to guard against mispointing, noise from the sun, rain attenuation, and equipment degradation).[52]

Reliability. Equatorial's reliability is expressed both quantitatively and through descriptions of network equipment and performance. Advertised as a reason for the "high reliability" of the network, Equatorial literature discusses bit error rates and the associated improved accuracy of the Equatorial network over terrestrial leased lines.[53] Since bit error rates are predominantly stated elsewhere in Equatorial literature as separate measures of performance not related to reliability, they are grouped separately under the category of "Bit Error Rate" (as discussed earlier in this chapter).

The majority of information related to Equatorial's reliability is stated in non-quantitative form. Equatorial states that "reliable transmission of data is assured by redundant electronics, an



Westar IV Footprint
Figure 2-4.

From: Equatorial Communications Company, <u>Point-To-Multipoint Data Communication Network Services</u>, Mountain View, California.

uninterruptable power supply and interference-resistant transmission techniques."[54] Additionally, remote monitoring and low power consumption allows its micro earth stations to operate reliably and unattended over long periods of time.[55] Spread spectrum technology coupled with the inherent reliability and redundancy of Equatorial's satellite network forms the basis for transmission accuracy and error recovery.[56]

Availability. Since its start of operation, Equatorial's spread spectrum network has maintained an availability of better than 99.9%.[57] This has been possible due to the use of backup satellite transponders, redundant electronics, multiple uplinks, and an uninterruptable power supply backed up with a diesel generator.[58]

Performance Comparisons

This section compares the three PSDNs based on the performance data obtained from each network. On the surface it would appear that networks generally provide the same specifications. Upon closer inspection, however, these specifications do not always correlate. Each performance parameter is defined and examined in terms of its importance to the telecommunications manager. Then the differences and similarities of each parameter are analyzed.

DATA RATES	
Transmission Capacity	150-19,200 bps
C-100 Data Rates	15-2400 cps
C-120 Data Rates	45-19,200 bps
Point-to-Multipoint I/O Mode Interfaces	
Asynchronous	45-9600 bps
Asynchronous/Synchronous	300-19,200 bps
Intelligent Programmable	300-19,200 bps
Interactive I/O Mode Interfaces	
Asynchronous	56.9-19,200 bps
Synchronous	2400-19,200 bps
Interactive Micro Earth Station	
Transmit	1200 or 9600 bps
Receive	19,200 bps
PROPAGATION DELAY	250 ms
BIT ERROR RATE	
Without Retransmission	1×10^{-7}
With Retransmission	1×10^{-12}
AVAILABILITY	99.9%

Summary of Equatorial Performance Data
Table 2-6.

Data Rates

Data rates describe the rate at which user information is passed through a data communication network. The data rate specification assists the telecommunications manager in network planning and resource sharing by indicating the capability of the network to handle the data transfer needs of his organization. All three networks published data rate information.

The DDN gives maximum data rates over its backbone network for three different types of circuits: Voice grade trunks, dataphone digital service, and analog trunks. Ranges of data rates are quoted for the access network, which covers host access circuits and Terminal Access Controllers. Ranges are also given for dedicated and dial-up line connections from the terminal to the Terminal Access Controller. All are stated in bits per second.

Telenet states maximum data rates for primary, secondary, and gateway trunks along its backbone. For connections to the network, ranges of data rates for dedicated and dial-up lines are given. All of Telenet's data rates are stated in bits per second except the secondary backbone network which is given in terms of T-1 carrier (1.544 Mbps).

Equatorial gives a transmission capacity range of data rates for the entire system as well as the C-100 and C-120 series micro earth stations. Also provided are data rate ranges for point-to-multipoint I/O mode interfaces and interactive I/O mode interfaces. Data rate quantities are quoted for maximum interactive micro earth station transmission and receive speeds. All data rates are given in bits per second except for the C-100 point-to-multipoint micro earth station, which is advertised in characters per second.

Because of the diversity of the three networks considered, the types of data rates given and manner in which they are expressed are quite different. All the networks, however, provide extensive information concerning data rate ranges or maximums for their interface, access, and backbone speeds. Although a majority of the data rates are expressed in bits per second, a few data rates given by Telenet and Equatorial are stated differently. Telenet's use of T-1 carrier to explain secondary trunk speeds on the backbone would be confusing if this service is not thoroughly understood. Equatorial's switch to characters per second on data rates for C-100 series micro earth stations does not equate easily to the bits per second used for the other rates, especially since the number of bits per character is not clear.

Delay

This measurement expresses the amount of time it takes a unit of information to travel from a source to a destination. It informs the telecommunications manager about the time delays that can be expected when attempting to transfer data through the network. Delays are provided by all three networks.

The DDN is very specific about its end-to-end delays across the backbone. Delay values, given in milliseconds, are quoted for the level of precedence assigned to the data traffic. Both high and low priority traffic delays are stated for the domestic network as well as connections from the United States through transoceanic satellite channels to overseas networks.

Telenet's average delay, as stated in Datapro, is expressed in tenths of a second. This delay does not include the time required for information to traverse the customer's network access lines.

Equatorial refers to delay across its network only through an article that was reprinted from Data Communications magazine. Confirmed by an Equatorial Product Manager, it is given in milliseconds and is the average propagation delay inherent in satellite communications systems. It applies only to the time required for data to travel from the transmitter through

the satellite to the receiver. Delays other than propagation delay are considered negligible.

All the delays given are averages that can be expected across the backbone of each network. How these averages are obtained and the exact start and end points used in their calculation are not identified in network literature. Most delay times are expressed in milliseconds, but the only reference to Telenet's delay is given in tenths of a second.

Response Time

Response time describes the time required to receive a response once an input is made in an interactive system. A glossary of data processing and telecommunications terminology defines this as the time between the end of a block of information input by a user and when the first character of system response is displayed on the terminal.[59] Telecommunications managers use response time to determine the delay expected through an interactive system. All three networks provide interactive service but only the DDN and Telenet provide information on response times.

DDN literature explains response time in an indirect way by saying it is 200 milliseconds more than response times experienced on other interactive systems using dedicated long-haul circuits.

Telenet advertises a response time for a complete end-to-end loop that ranges from 300 to 500 milliseconds. A Telenet Systems Engineer also quoted figures for the average call set-up and coast-to-coast call set-up delays, and explained that they are measured from the carriage return to reception of the first byte back to the terminal. All values are expressed in milliseconds.

The fact that Equatorial does not publish a response time seems to indicate that it is either considered unimportant or it is an indicator of network performance the company does not wish to advertise. Although response times of the other two networks are stated in the same units of measure, it is difficult to compare them because of the way they are presented. The response time given for the DDN is hard to determine because it is presented in terms of, and therefore dependent on, a variable response time quantity that is calculated with an unspecified method. Also, because a definition of Telenet's end-to-end loop is not stated, the exact start and end points used in taking the measurement are not known. Because it is not clear if the two response times are representing the same information, the problem of comparing them is compounded.

Bit Error Rate

The bit error rate of a network relates to the proportion of erroneous bits that are found in a given sample. To the telecommunications manager, it is a measure of the quality of the system and expresses the ability of a network to pass data without errors.[60] All of the networks give bit error rates, each under a different heading.

The DDN refers to its undetected error rate under the heading of "Accuracy". This rate is expressed quantitatively (4.2×10^{-18}), as well as in statement form for easy understanding. This undetected error rate is calculated after the automatic retransmission of any detected bit errors. The method used by the DDN for determining undetected errors is not given.

Telenet's error rate is mentioned under the "Error Detection Effectiveness" of the network. It is not given as a quantitative number but rather as a statement that there is "approximately one bit error for every 10^{12} bits sent" which equates to a bit error rate of 10^{-12}. Telenet claims that the statistical/error test applied in the X.25 protocol is why the bit error rate is so good.

Equatorial's error rate is simply called the "Bit Error Rate". Two bit error rates are given, each as a quantity and as a statement. The smaller bit error rate

stated for the C-200 series micro-earth station is obtained through the automatic retransmission of incorrect messages after bit error detection. Although not stated, it is assumed that the larger bit error rate is before retransmission of detected errors because the other bit error rate is smaller and retransmission of detected errors is given as the reason. Graphics used by Equatorial in company literature shows the boundaries around the United States within which Equatorial dishes will operate with a bit error rate of at least 10^{-5}. The relationship of this information with the better bit error rates stated earlier in this chapter is not clear.

Although all three networks provide information on error rates, the terminology used to express it and the manner in which it is presented creates problems in its interpretation. Each network refers to their bit error rate with a different name or places it under a different heading. Although each network attempts to aid understanding by stating error rates in layman's terms, the quantitative values given are not expressed in similar manners. Some are quantities like "10^{-12}" while others are given as "one out of 10^{12}".

Interpretation of the error rates is difficult because some are calculated before automatic retransmission of detected errors and some are calculated after retransmission of detected errors. The DDN gives

an error rate after retransmission, while Equatorial states error rates for both before and after retransmission. Telenet, on the other hand, only gives one bit error rate which is assumed to be calculated after retransmission of detected errors. Also, since the methods for measuring these quantities are not stated, it is not certain that they represent identical information.

Reliability

Reliability describes the "probability that a device will perform without failure for a specified time period or amount of usage".[61] It is also known as a measure of a system's ability to perform within certain acceptable limits. A telecommunications manager judges a network's reliability to determine if it will consistently meet the time and quality requirements of his organization's data network. The DDN provides a quantitative measure of reliability, Telenet simply discusses it, and Equatorial connects it to the bit error rate as well as discusses it.

Under the title of "Reliability", the DDN gives a value for the accidental misdelivery of a data unit. This value expresses the probability that a packet will arrive at an undesired destination rather than a desired one. The method of determining this probability, and how

it relates to the automatic retransmission detected errors, is not covered.

Although Telenet does not provide quantitative measures of network reliability, company literature does discuss reliability in terms of network configuration and customer support. Dynamic alternate routing and maximum loading constraints over the backbone, as well as 24-hour, 7-day a week customer support and network management functions, are Telenet's reasons for advertising a high degree of reliability.

Equatorial's reliability is stated more qualitatively than quantitatively. Redundant equipment, spread spectrum technology, and the inherent qualities of satellite transmission are the main bases for determining the degree of Equatorial's reliability. Quantitatively, however, Equatorial does mention the bit error rate as an indicator of system reliability also. But since it is stated as an independent performance parameter in other Equatorial literature, it is analyzed under a previous section of this chapter titled "Bit Error Rate".

In analyzing the reliability information presented, several problems arise. The DDN's probability for the accidental misdelivery of a packet does provide a quantitative means by which to judge the network. However, it is questionable whether it can be used to judge reliability with respect to the definition

previously given. The probability that a system will operate without failure does not necessarily correlate with the probability of accidental packet misdelivery, except in a very liberal interpretation of the words "without failure" as used in the given definition. Even in the liberal sense, the accidental misdelivery of a packet only covers one possible aspect of a system's total reliability. Since quantitative reliability measurements are not stated by Telenet, and only alluded to as a part of Equatorial's reliability, comparisons of reliability for these networks are difficult. The fact that each network uses different configurations, functions, and services to discuss their reliability only compounds the problem, and points out the differences each network has in defining reliability.

Availability

Availability is the degree to which a system is ready when called on to process data.[62] It is used by telecommunications managers to predict the probability that the network will not be operating when data communications services are requested. All three networks provide an availability measurement.

The DDN quotes network availabilities for both single homed and dual homed users. Single homed users have only one path by which to access the network while

dual homed users have two. Dual homing allows network access in the case one access path is inoperable. Both quantities are given as percentages.

Telenet describes its availability in two different ways. The first, as with the DDN's availability, is a percentage. An independent availability percentage is stated for both the network and the switches. The second way used to express local access availability is the public dial-in grade of service. Grade of service determines the probability that a user will not be able to access the network through a dial-up line because of blocking in the Public Switched Telephone Network. Blocking occurs when the number of users desiring service through the network exceeds the networks ability to provide that service. In the case of GTE Telenet, they express a P.01 grade of service. This means that, using Poisson blocking formulas, there is a 1.0% chance that a user will not be able to access the Telenet network during the busiest calling hour of the day.

Equatorial also states its measure of availability as a percentage. From Equatorial literature, it appears to be calculated by dividing the total amount of time the system has been capable of providing service by the total time the system has been operational. Redundant and backup equipment are given as

the reasons for Equatorial's high percentage of availability.

Because availability is a function of a network's ability to continue working in the event of equipment failure, each network discusses redundant, backup, and alternate systems and equipment when it is mentioned. All availability values seem to express the percentage of time the network is operating and available for user access. How the percentage values for the DDN and Telenet are calculated is not given, and the source of Equatorial's availability can only be assumed based on statements made in its literature. Finally, Telenet's use of grade of service to help describe availability appears to be misplaced since it relates to the probability that a call will be blocked as opposed to the probability that the network is not working.

National Standard Comparison

On February 22, 1983, the Board of Standards Review of the American National Standards Institute (ANSI) voted to approve publication of American National Standard X3.102, "Data Communication Systems and Services: User-Oriented Performance Parameters."

The American National Standard X3.102 User Reference Manual, written by N. B. Seitz and D. S. Grubb and published by the Department of Commerce in 1983,

provides an excellent informal and non-technical presentation of objectives and content of ANS X3.102. A majority of this section is taken from this document.

Following a brief description of the standard, each parameter is defined. Then the data provided from each of the three PSDNs being evaluated is correlated with the parameters of this standard.

ANS X3.102

Having evolved from the earlier Interim Federal Standard 1033, ANS X3.102 defines a set of parameters that provide a uniform means of specifying the performance of data communication systems and services. Because these parameters can be applied to any digital communication system or service, irrespective of transmission medium, network topology, or control protocol, these parameters are extremely useful in performance comparison and user requirements specification.[63]

Performance Parameters

There are 17 primary and 4 ancillary parameters defined by ANS X3.102. The ANS X3.102 parameters are user dependent and therefore the user contribution to their measurement needs to be accounted for. This is accomplished by dividing the total performance time for

an associated function into alternating periods of system and user responsibility. Primary parameters pertain to that fraction of time attributed to the communications system or service and ancillary parameters to the time contributed by the user. While it is helpful to understand the effect ancillary parameters have on the performance evaluation of a network, this study limits discussion to only primary parameters. Table 2-7 presents these parameters with respect to function and performance criteria. For each parameter, a brief description is provided below.

Access Time. This is the average time the user must wait after requesting data communication service for the system to begin accepting user information for transmission. Access time begins on issuance of an access request or its implied equivalent at the originating user/system interface. It ends when the first bit of source user information is input to the system.[64] Typical values for this parameter range from 0.15 to 4.0 seconds for a PSDN.[65]

Incorrect Access Probability. This is the probability that user information will be transmitted on an improper path as a result of a system error during the access process. It is expressed as the ratio of total incorrect access outcomes to total access attempts.[66]

<table>
<tr><th rowspan="2">FUNCTION</th><th colspan="3">PERFORMANCE CRITERION</th></tr>
<tr><th>SPEED</th><th>ACCURACY</th><th>RELIABILITY</th></tr>
<tr><td>ACCESS</td><td>Access Time</td><td>Incorrect Access Probability</td><td>Access Denial Probability

Access Outage Probability</td></tr>
<tr><td rowspan="2">USER INFORMATION TRANSFER</td><td rowspan="2">Block Transfer Time

User Information Bit Transfer Rate</td><td>Bit Error Probability

Bit Misdelivery Probability

Extra Bit Probability

Block Error Probability

Block Misdelivery Probability

Extra Block Probability</td><td>Bit Loss Probability

Block Loss Probability</td></tr>
<tr><td colspan="2">Transfer Denial Probability</td></tr>
<tr><td>DISENGAGEMENT</td><td>Disengagement Time</td><td colspan="2">Disengagement Denial Probability</td></tr>
</table>

Summary of ANS X3.102 Performance Parameters
Table 2-7.

From: N. B. Seitz and D. S. Grubb, U. S. Department of Commerce, American National Standard X3.102 User Reference Manual, Boulder, Colorado, October 1983.

While there is little system performance data on this parameter, a reasonable value for packet-switched networks utilizing a 32-bit Cyclic Redundancy Check would be about 10^{-10}.[67]

Access Denial Probability. This is the probability of system blocking during access.[68] Closely related to "Grade of Service" or "Blocking Probability" in circuit-switched systems, a probability between one to five percent is generally acceptable in applications where data aging is slow. However, values in the 10^{-2} to 10^{-3} range may be needed in critical real-time applications.[69]

Access Outage Probability. This is the probability that the system will be in an outage state which prevents it from responding to the originating user on any given access attempt. The ratio of total access attempts that result in access outage to total access attempts, the Access Outage Probability is closely associated with the concept of "availability".[70] Typical values for this parameter range in the 90% to 99.9% range with values above 98% being more common.[71]

Bit/Block Error Probability. This is the probability that a unit of information transferred from a source user to the intended destination user will be delivered in error. It is the ratio of information units

(bits or blocks) delivered to the intended destination user with content errors to the total number of units transferred.[72] Bit and Block Error Probability are about the most widely used data communication performance parameters. These parameters apply to end-to-end services and therefore reflect the error-producing or error-removing effects of data terminals and higher level protocols. Therefore, both parameters measure errors that remain after error control. Depending on a particular application's requirements, typical values for this parameter range from 10^{-5} to 10^{-8}.[73]

<u>Bit/Block Misdelivery Probability</u>. This is the probability that a unit of information transferred from source user A to destination user B will be delivered to some destination user other than B. This probability is the ratio of misdelivered information units to the total number of information units transferred.[74] Again, the values for this parameter vary depending on the particular application. When the content of the data being sent is extremely sensitive, techniques are used to keep this value around 10^{-9}. For less critical data, normal error control techniques help keep this value around 10^{-5}.[75]

<u>Bit/Block Loss Probability</u>. This is the probability that a system will fail to deliver a unit of

information output from a source user to the intended destination user within a specified maximum transfer time. This probability is the ratio of the number of information units lost as a result of system performance failures to the total number of information units output by the source.[76] A reasonable value for this parameter can range from 10^{-5} to 10^{-8}.[77]

Extra Bit/Block Probability. This is the probability that a unit of information delivered to a destination user will contain duplicate bits of information or other extra information not output by the source user.[78] Again, data on user requirements for this particular variable is scarce. Studies suggest that a value from 10^{-10} to 10^{-11} for interactive data communication services is reasonable.[79]

Block Transfer Time. This time expresses the total delay a user information block experiences in transit between users. It is the average value of elapsed time between the start of a block transfer attempt at the source user and successful block transfer at the destination user.[80] Block Transfer Time is separated into three components: modulation time, propagation time, and storage time.[81] As might be guessed, storage time accounts for the majority of this parameter. For simple circuit-switched systems with

unbuffered terminals, values in the range of 30 to 100 milliseconds are typical. Connection-oriented systems with buffered terminals have times usually in the 100 to 300 millisecond range.[82] The ARPANET, predecessor to the DDN, was designed for end-to-end delays not to exceed one-half second for typical messages of a few thousand bits.[83]

User Information Bit Transfer Rate. This is the rate at which user information is transferred through a data communication system. It is the slower of two rates: (1) the rate at which user information is passed from a source user to the system, and (2) the rate at which the same user information is passed from the system to the destination user.[84] Here, the particular application has an important role in determining an appropriate user specification for this parameter. For example, it would make little sense to specify a data rate of 2400 bits per second if the input rate is restricted to the source user's typing speed of 35 bps. However, for computer to computer applications, such a rate may actually restrict the flow of information.

Transfer Denial Probability. This is the probability that there will be an unacceptable degradation in the performance of a data communication service during user information transfer. This may be in

the form of unacceptably poor transmission quality or unacceptably low throughput. Complete disconnection of communicating users reduces the throughput to zero and is thus included as a limiting case. This probability is the ratio of total transfer denials to total transfer attempts where a transfer denial is defined to occur whenever the performance observed is worse than the threshold of acceptability for any of the parameters for user information transfer.[85] This parameter is closely related to the concept of reliability. "Based on inference from specified values for availability, it appears that user requirements for Transfer Denial Probability may range from 10^{-2} to 10^{-5}."[86]

Disengagement Time. This is the average time a user must wait, after requesting disengagement from a data communication session, for the system to successfully accomplish the disengagement function. Computation of disengagement time begins with issuance of a disengagement request and ends either when the user receives some sort of disengagement confirmation or when the user is next able to initiate a new access attempt.[87] Kimmett and Seitz have calculated typical disengagement times of 0.5, 1.5, and 2.25 seconds for non-switched, message-switched, and circuit-switched services respectively.[88]

Disengagement Denial Probability. This is the probability that a system will fail to detach a user from a session within a specified maximum time after issuance of a disengagement request. This is the ratio of total disengagement attempts that result in denial to total disengagement attempts exclusive of those attempts that end in blocking.[89] User requirements for this parameter depend on the service usage pattern. In polling applications, low values are appropriate. Much higher values can be tolerated where usage is usually preceded by a long idle period.[90] A study by Nesenbergs, Hartman and Linfield suggests a value of 10^{-3} for interactive packet-switching network users.[91]

Network Compliance

So far, this chapter has listed the available performance specifications of the DDN, Telenet, and Equatorial and analyzed them in regards to their similarities, differences, and meanings. Also, it has discussed the American National Standard X3.102 , which provides a uniform means of identifying the performance of data communications systems, and briefly defined its seventeen primary parameters.

This section will compare the network provided performance specifications with the ANS X3.102 parameters to determine the degree of network compliance

with the standard. Each network performance specification will be analyzed and graded in terms of full compliance, partial compliance, or non-compliance with the standard.

Data Rates. The data rates provided by the networks most closely relate to the ANS X3.102 parameter of User Information Bit Transfer Rate. Both express the rate at which information is passed through the network; however, the ANS parameter is more restrictive in definition. The data rates specified by the networks relate to transmission speeds at the data terminal equipment/data circuit-terminating equipment (DTE/DCE) interface. Normally these rates are for continuous input and output, and include overhead bits not sent to the end user. The User Information Bit Transfer Rate is more specific in that it is the slower of two rates: (1) the rate that a user's input enters the system or (2) the rate that user information arrives at its destination. It is expressed in bits per second and, since it does not include system overhead, is a better measure of actual user-to-user throughput. The User Information Bit Transfer Rate is usually 20 to 50 percent lower than traditionally advertised data rates.[92]

A comparison of the various methods of expressing the rate of data flow through a network reveals several things. Each of the networks provides some type of

information with regards to data transfer; however, it is not presented along the guidelines given for the User Information Bit Transfer Rate found in ANS X3.102. Additionally, two of the networks used units of measurement other than bits per second to express some of their data rates. This also does not comply with the standard. The fact that information is provided by the networks concerning data flow, but is not presented in accordance with the standard, gives all three networks a rating of partial compliance for this parameter.

Delay. The delay times of each of the networks are very similar to the ANS X3.102 parameter of Block Transfer Time. They both inform the user about the expected time in seconds required to pass information from one place to another in a data communications network. The differences between them are the start and stop points used to calculate the delay. All three networks provide delay times that only apply to their backbone network, which does not include the user access lines. Block Transfer Time, on the other hand, expresses the total delay experienced by a user information unit from the time it leaves the source to the time it arrives at the destination. As explained earlier, the Block Transfer Time includes modulation, propagation, and storage time.

Analysis of network delay times in relation to the ANS X3.102 parameter of Block Transfer Time again shows some basic differences. The DDN's delays are for end-to-end connections across the network's backbone; Telenet's delay does not include customer access lines; and Equatorial's delay is strictly the normal propagation time inherent in satellite systems. Since these values do not include other delays contained in the Block Transfer Time parameter, all three networks receive a grade of partial compliance in this category.

Response Time. Response time, as provided by the networks, is not specifically addressed by ANS X3.102. Since the response time is used in interactive systems to express the delay that occurs between a user input and the resulting response, it is closely related to a value twice the size of the Block Transfer Time. Because of the similarity between response time and the Block Transfer Time, the information provided by the networks for this specification will be analyzed with reference to the Block Transfer Time to determine if a higher grade of compliance can be obtained for that parameter.

Only two of the networks provided response time values. The response time given by the DDN is stated in indirect terms and therefore does not help to clarify delays over the network. Telenet's published range of response times is so broad that it also fails to add

clarity to its network delay. This is the case for the more exact Telenet response time information as well. Since no additional information about delays is contained in the response time specifications, all three networks' grade for Block Transfer Time remains the same.

Bit Error Rate. Although the bit error rates provided by the networks are referred to under different headings, they closely resemble the Bit Error Probability defined in ANS X3.102. Both the bit error rate and Bit Error Probability express the possibility that information transferred from a source will arrive at the destination with incorrect binary information.

A comparison of the Bit Error Probability with the network's bit error rates shows some slight differences. The Bit Error Probability is expressed as a number between zero and one, with quantities like 10^{-10} being common. Telenet gives its bit error rate in a reciprocal manner by stating it as "one bit error for every 10^{12} bits sent." Another difference is that Equatorial provided bit error rates that pertained to measurements taken both before and after retransmission of detected errors. Measurements taken before retransmission of detected errors do not equate to the ANS X3.102 parameter because Bit Error Probability is measured after error detection and correction is performed. Despite small differences between the bit

error rates given by the networks and the Bit Error Probability of the standard, a grade of full compliance is awarded to all three networks for this parameter.

Reliability. The definition of reliability as presented by the networks relates to several parameters in ANS X3.102 that are grouped under the general performance category of "reliability". Access Denial Probability and Access Outage Probability are two of these parameters that have already been discussed. Looking at the reliability information provided by the networks, most of it is given in qualitative form. Among the three networks, the only quantitative measure for reliability is given by the DDN and is called the accidental misdelivery of a data unit. This specification does not relate to any of the ANS X3.102 parameters grouped under "reliability", but compares very well to Block Misdelivery Probability found under the heading of "accuracy". Both parameters provide information relating to the proportion of user information segments that are delivered to a destination other than the one desired.

Although the DDN does not provide information on how the accidental misdelivery of a data unit is calculated, it appears that this measurement is almost identical to the Block Misdelivery Probability. The accidental misdelivery of a data unit is stated as a

number between zero and one so no mathematical conversion is necessary to state it as a Block Misdelivery Probability. It appears the DDN is in full compliance with this parameter.

Availability. The availabilities expressed by the networks almost directly match with the ANS X3.102 parameter of Access Outage Probability. Both relate to the possibility that a system will be inoperable when called upon by a user to transfer data.

The only difference between the availabilities given by the networks and the Access Outage Probability is in the methods in which they are expressed. The Network availabilities are given as percentages, while the Access Outage Probability is expressed as a value between zero and one. A simple mathematical conversion is all that is required to transform the networks' availabilities into Access Outage Probabilities. Due to the similarity of availability and Access Outage Probability, the three networks are considered to be in full compliance with this parameter.

In addition to the percentage value provided for availability, Telenet also provided a grade of service to express its availability. Telenet's grade of service specification relates very well to the ANS X3.102 parameter of Access Denial Probability. Both express the likelihood that blocking will occur during system access.

Telenet's grade of service is given in conventional blocking terminology, such as P.01, and can be easily converted into a number from zero to one to obtain the Access Denial Probability. But, because Telenet quotes a grade of service only for its dial-up connections, and not for any other types of service, it is graded as being in partial compliance with the standard.

Overall Compliance. An analysis of the preceding data reveals that only six of the seventeen primary parameters of ANS X3.102 are addressed by the networks in their published performance specifications. This means that the networks receive a grade of non-compliance for the remaining eleven primary parameters not covered.

To determine a quantitative measure of each networks's compliance with ANS X3.102, the following assignment of points and calculations are used. For each parameter that a network shows full compliance with, one point is awarded. For each partial compliance, a half point is awarded and no points are awarded for non-compliance of a parameter. Using this method, the DDN is awarded 4.0 points out of seventeen, Telenet is awarded 3.5 points, and Equatorial is awarded 3.0 points. Dividing these assigned point values by the total number of points available (17 total) gives an approximate percent of compliance of the networks with ANS X3.102.

Table 2-8 shows a summary of the network's compliance with the American National Standard.

ANS X3.102 Parameters		DDN	Telenet	Equatorial
SPEED	Access Time			
	Block Transfer Time	PC	PC	PC
	Bit Transfer Rate	PC	PC	PC
	Disengagement Time			
ACCURACY	Incorrect Access Prob.			
	Bit Error Prob.	FC	FC	FC
	Block Error Prob.			
	Bit Misdelivery Prob.			
	Block Misdelivery Prob.	FC		
	Extra Bit Prob.			
	Extra Block Prob.			
RELIABILITY	Transfer Denial Prob.			
	Disengagement Denial			
	Access Denial Prob.		PC	
	Access Outage Prob.	FC	FC	FC
	Bit Loss Prob.			
	Block Loss Prob.			
Compliance		23.5%	20.6%	17.6%

Blank = Non-Compliance
PC = Partial Compliance
FC = Full Compliance

Compliance with ANS X3.102 Performance Parameters
Table 2-8.

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CHAPTER III

SARNET APPLICATION

The lack of comparability and the lack of standardization among performance specifications makes an evaluation of the three networks difficult at best. This, and the fact that the SARNET requirements have been based upon a Statement of Work that is both limited in the number of actual performance requirements, and specifically written to procure PSDN services from GTE Telenet, makes this analysis even harder.

Despite these obstacles, this chapter evaluates the performance specifications from each of the three different packet-switched data network implementations in terms of the user's performance requirements. First, the user requirements are listed. Then, each representative network is evaluated with respect to these requirements.

SARNET Requirements

This study attributes the limited number of actual performance requirements in the statement of work to the fact that the pilot SARNET program is only for demonstration and evaluation purposes. Since the goal of this Demonstration and Evaluation is to quantify and

estimate the advantages of using packet-switched technology, it is assumed that the requirements for the final SARNET system will be expanded and fine-tuned based on these findings. Therefore, this study does not strictly adhere to the requirements laid out in the Statement of Work for the pilot SARNET system, but has adjusted them for the purpose of this evaluation.

The SARNET requirements are separated into performance and non-performance specifications. Although of equal importance, the analysis of the non-performance criteria is purposely kept brief to avoid detracting from the evaluation of the performance criteria.

Performance Specifications

The performance requirements for the SARNET system, summarized below in table 3-1, were based on specifications obtained from a Statement of Work drafted

REQUIREMENT	SPECIFICATION
Data Rates	4800 & 9600 bps network access
Network Delays	250 ms average, 2 second maximum
Bit Error Rate	10^{-9}

Summary of SARNET Performance Requirements
Table 3-1.

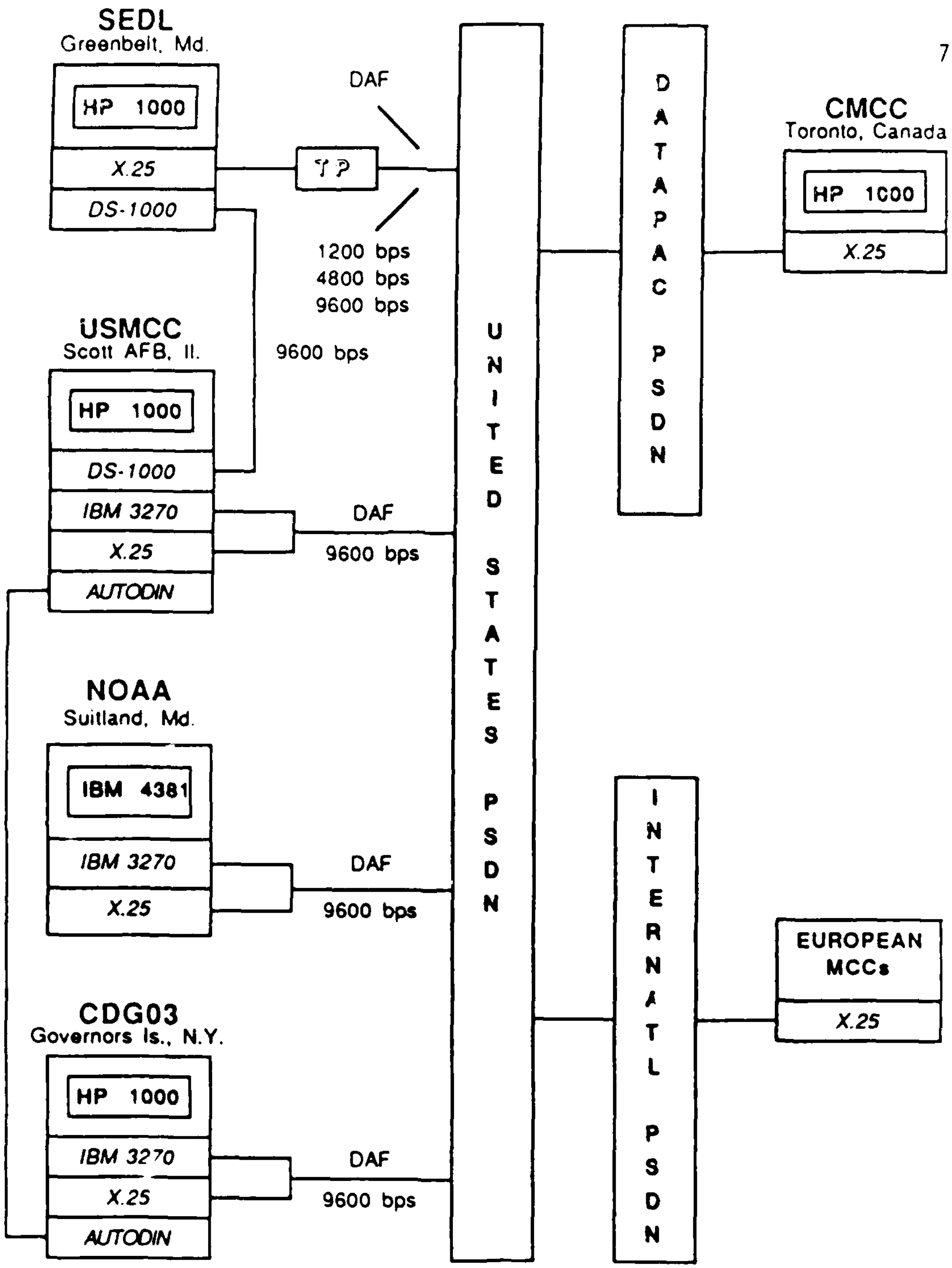
FROM: NOAA/NESDIS, draft Statement of Work for the procurement of PSDN services in support of the SARSAT system, 1986.

by the National Oceanic and Atmospheric Administration for the procurement of PSDN services.

Data Rates. Data rates needed to support the pilot SARNET system range from 1200 bps for the Systems Experimental Development Laboratory (SEDL) at the Goddard Space Flight Center in Suitland Maryland to 9600 bps for the United States Mission Control Center at Scott Air Force Base in Illinois.[1] Figure 3-1 shows the network configuration, including data rate requirements, for the pilot SARNET system. For the purpose of evaluation, this study uses data rates of 4800 and 9600 bits per second as the requirement for access to the PSDN.

Network Delays. The network is expected to have a maximum delay, including any contemplated satellite service, of 2.0 seconds or less. Average network delay is not to exceed 250 milliseconds.[2] This specification requires further clarification. It is not clear if these delays refer to only the backbone network or whether they include the access network as well. For the purpose of this evaluation, it will be assumed to include both the access and backbone networks.

Bit Error Rate. Using appropriate error detection and correction techniques, undetected errors in the network shall not exceed one in 10^9 bits of data transmitted.[3] This specification should require no



SARNET Pilot System
Figure 3-1.

From: NOAA/NESDIS, U. S. Department of Commerce, Pilot Program Plan for the SARSAT Search and Rescue Communications Network (SARNET), draft, Washington D. C., February 1986.

additional explanation; however, because Equatorial provides this figure for both before and after retransmission of detected errors, there could be some ambiguity in the analysis of this requirement. For this evaluation, only Bit Error Rates that apply to service after retransmission of detected errors are considered.

Availability. This performance measurement was not put into quantitative terms; however, it is stated that "network services shall continue to be fully available during any preventive maintenance to the PSDN and the users connection to it."[4] In order to evaluate this requirement, this study will use the typical values (90% to 99.9% - with 98% being most common) given in ANS X3.102 for Access Outage Probability as a guideline.

Non-Performance Specifications

The following is a combination of the other non-performance user requirements that are also considered in this analysis.

Locations Supported. The pilot SARNET system will interconnect the SEDL at NASA's Goddard Space Flight Center, the Information Processing Division (IPD) of NOAA/NESDIS, the USMCC at Scott Air Force Base, and the 3rd Coast Guard District (CGD) at Governor's Island in New York.[5] In addition to these locations, the PSDN must

provide future network services to the remaining Rescue Coordination Centers and Local User Terminals.

Gateway Facilities. The SARNET requires the capability for data exchange via gateways with other PSDNs in the United States, Canada and Europe. These gateways will use the CCITT X.75 standard. These connections are required for the demonstration and evaluation of the international portion of this search and rescue network. In addition to the PSDN gateways, a gateway to TELEX facilities is needed.

Access Facilities. Due to the critical nature of the data, dedicated access facilities will be necessary. To allow for interoperability of the various data systems within the SARSAT system, access to the PSDN must allow both IBM 3270 and X.25 synchronous protocol connections.

Network Management and Control. For the purpose of the SARNET pilot program, access to the PSDN will be controlled and monitored from some kind of network management and control facilities. These facilities must perform early detection of possible line problems, answer user questions about network access and operation, generate appropriate performance reports, and take corrective action in cases of equipment or line failure. The network management and control facilities must operate 24 hours per day, 7 days per week.

Network Maintenance. The PSDN must provide maintenance services for the access portion of the network 24 hours a day, 7 days a week. Response time to maintenance calls must not exceed 4 hours. Network services must remain fully available to the user during any preventive maintenance to the PSDN.

System Security. The PSDN must support security measures which incorporate identification codes and passwords for individual users to facilitate SARSAT system security measures.

Network Usage Reports. To help in the evaluation of PSDN services in support of the SARSAT mission, the network must provide monthl' detailed connection reports.

Evaluation of Alternatives

Using the performance specifications provided by each network and realizing that there is not always a one-to-one correspondence of network specification to user requirement, this analysis evaluates each packet-switched data network with respect to its ability to meet the SARNET requirements listed above.

Defense Data Network

The Defense Data Network, based on packet-switched technology developed by the Defense Advanced

Research Projects Agency, represents the military implementation of a PSDN. Keeping in mind that the DDN is designed with the unique military requirements of survivability, precedence and preemption, an analysis of the network's performance follows.

<u>Data Rates</u>. The DDN supports host access data rates ranging from 4,800 to 56,000 bits per second. This meets the requirement for the future SARNET system.

<u>Network Delays</u>. The average backbone network delay for low precedence traffic within the United States is 0.122 seconds and 99% of this traffic has a delay of less than 0.5 seconds which is well below the SARNET maximum for these requirements. If the delay encountered through the access network is not excessive, the DDN should be able to meet this SARNET performance requirement.

<u>Bit Error Rate</u>. The bit error rate quoted for the DDN (4.2×10^{-18}) far exceeds the requirements stated for the SARNET system.

<u>Availability</u>. The DDN claims availability figures of 99% and 99.95% for single and dual-homed users respectively. These figures are well within the range of reasonable performance and should exceed the SARNET requirements.

Locations Supported. Each of the Local User Terminals and Rescue Coordination Centers is located near or on a Coast Guard or Air Force facility. The proximity to these facilities provides close access to the DDN network services.

Gateway Facilities. While the DDN does support standard implementation of commercial X.25 products, the user is restricted to a single subnet of the DDN.[6] In other words, internet capabilities using the CCITT [illegible] protocol standard are not supported by the DDN. [illegible] unless the Datapac and European PSDNs support the [illegible] specialized Internet Protocol (IP), implementat[illegible] SARNET system would be limited to the United States.

Access Facilities. The DDN not [illegible] dedicated access facilities but also [illegible] CCITT Recommendation X.25 (the 1984 [illegible] X.25 is not supported).[7] As for the [illegible] equipment to the DDN, interfa[illegible] to DDN's specialized transm[illegible] protocols are commercia[illegible]

Network Manage[illegible]

Network Mon[illegible]

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AND RESCUE COMMUNI..(U) AIR FORCE INST OF TECH
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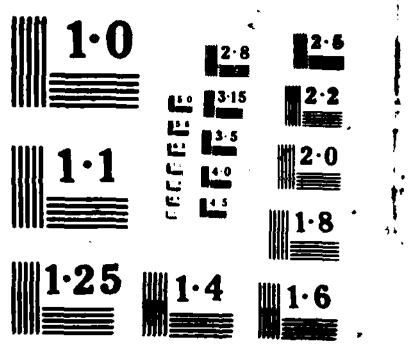
1·0
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1·1
2·0
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1·25
1·4
1·6

fault isolation and diagnostics; (3) updating and maintaining static and dynamic information about network elements; and (4) presenting system events in formats best suited to the user.[8] This should meet the SARNET management and control requirement.

Network Maintenance. As quoted above, the Network Monitoring Center provides continuous monitoring of most of the various network components; however, it cannot monitor terminal access circuits at the Terminal Access Controller or host access circuits connecting X.25 implementations.[9] In addition, response to network hardware problems can range from two to twelve hours depending on the location and proximity to field offices, and circuit problems can have response times of up to 24 hours.[10]

System Security. The DDN provides its users with an extensive security architecture that includes: link encryption of the backbone trunks; access control to the Terminal Access Controllers; and TEMPEST certification of access and switching nodes. Nevertheless, these measures do not provide for identification codes and passwords for individual users.

Network Usage Reports. The Network Monitoring Center has the capability of gathering statistical data on throughput and reporting the status of various network

components. It is not clear that detailed information is available in the format desired for the SARNET.

Summary. The Defense Data Network provides PSDN services with the performance necessary to meet most of the requirements of the SARNET system. However, analysis of the other non-performance criteria reveals that the DDN may not provide the flexibility needed to meet the other demands of this international project. These include the DDN's inability to meet the requirements of gateway access using the CCITT recommendation X.75 protocol, guaranteed four hour maintenance response time, network monitoring of X.25 circuits, and desired security precautions. It is also unclear whether detailed connection reports would be available.

GTE Telenet

Telenet is the largest commercial packet-switched network of its kind in the world. As such, it is an excellent representative for the commercial terrestrial PSDN needed for comparison in this study. Remembering that the Statement of Work for the SARNET was written with Telenet in mind, Telenet meets the requirements as follows.

Data Rates. Telenet offers packet-switched data communication services for dedicated synchronous

transmission speeds ranging from 2400 to 56,000 bits per second. This meets the SARNET system requirement.

Network Delays. Telenet does not advertise a maximum delay time for messages traversing its network, therefore, without further information, it is uncertain if Telenet can meet the SARNET maximum delay time of 2.0 seconds. Telenet's average delay time of 0.2 seconds does not consider transit times across customer network access lines; however, it is sufficiently low enough that, if moderate customer access delays were added, the average delay would still meet the SARNET requirement.

Bit Error Rate. Telenet's advertised bit error rate is 10^{-12}, which is assumed to be measured after retransmission of detected errors. This bit error rate meets the SARNET requirement.

Availability. Although the SARNET requirement does not state quantitative values for availability, Telenet's network availability of 99.9% and switch availability of 99.995% should be more than adequate for the system.

Locations Supported. Telenet provides network access through approximately 200 Telenet Central Offices (TCOs) across the United States.[11] The locations listed for the pilot SARNET system, plus any possible future

SARNET node shou'' be easily connected through these TCOs.

Gateway Facilities. Access to Telenet is offered in almost 70 countries through the Postal, Telephone, and Telegraph (PTT) administrations of those countries where service is available.[12]

International access is available through interconnection to packet-switching gateways and the domestic networks in these foreign countries using the X.75 protocol.[13] Worldwide access to the network is also available through Telex facilities.[14]

Access Facilities. Telenet provides dedicated access facilities for connection to the network. It also allows IBM 3270 and X.25 synchronous protocol connections.[15]

Network Management and Control. Telenet has a Network Control Center located in Reston, Virginia that provides extensive network diagnostic, monitoring, and recovery capabilities, both manual and automatic. It operates continuously and, with the aid of Telenet Processor Reporting Facilities (TPRFs) provides messages and reports on several events happening in the system, either on demand or when required.[16]

Network Maintenance. Telenet's Customer Service operates 24 hours a day, 365 days a year for the sole purpose of responding to problems in the network. Problems not automatically corrected by the Network Control Center can be relayed to Customer Service through a toll-free telephone number and are usually corrected during the phone call. For more extensive problems, maintenance support personnel located in over 110 cities across the country are available on a moment's notice to help in solving them. DDS link outages are normally repaired in less than an hour while analog links are usually repaired in 3 1/2 hours or less.[17] Any issue taking more than 24 hours to solve is brought to the attention of the vice president and general manager of the network. Preventive maintenance does not interfere with normal network business and takes no more than 30 minutes to perform.[18]

System Security. Telenet provides security measures that include user identification codes and passwords. They also have a dedicated security office that works to detect and correct any violations of security.[19]

Network Usage Reports. As an additional supplement to the monthly invoice, users can purchase Telenet's Detail Connection Report. It is available in

printed or magnetic tape form and provides detailed analysis and monitoring information that can be used for accounting purposes.[20]

Summary. As expected, Telenet appears to meet or exceed the requirements for the SARNET system in almost every instance. It is unclear whether Telenet meets the given requirement for maximum network delay. Concerning this area of uncertainty, it is assumed that Telenet can meet the requirement, and that the information provided by Telenet for this study is just not specific enough to provide a definite answer.

Equatorial Communications Company

Equatorial operates the largest commercial satellite-based data communications network in the world. With plans underway to expand its influence into international markets, Equatorial is a good choice for this study's satellite-based packet-switched data network. The following shows how Equatorial meets the requirements of the pilot SARNET system.

Data Rates. Point-to-multipoint connections using the C-100 and C-120 series micro earth stations allow synchronous transmission speeds ranging from 300 to 19,200 bps. Interactive networking using the C-200 series micro earth stations permits synchronous

interfacing from 2400 to 19,200 bps. Transmissions from the interactive earth stations can operate at 1200 or 9600 bps. Depending on the configurations used, Equatorial should be able to provide the data rates required.

Network Delays. Equatorial's inherent propagation delay for one-way transmission averages 250 milliseconds. Other delays due to buffering and access are relatively small, but would add to this propagation delay to increase the average delay from end-to-end to over 250 milliseconds. As a result, this delay just barely fails to meet the SARNET requirement for an average delay of 250 milliseconds.

Bit Error Rate. From the information provided, it appears that the C-100 and C-120 series receive only micro earth stations provide a bit error rate of 10^{-7} and therefore fail to meet the SARNET requirement. The C-200 series micro earth stations, with error detection and automatic retransmission capabilities, qualify for the SARNET with a bit error rate of 10^{-12}.

Availability. Equatorial's advertised availability of 99.9% appears to meet this requirement.

Locations Supported. Presently, any location within the footprint of the satellites used by Equatorial

can be connected to the network. All four of the pilot SARNET locations can be connected. With Equatorial's expansion into the international arena, service may also be available for world-wide networking.[21]

Gateway Facilities. Current information provided by Equatorial states that the Intelsat Board of Directors has tariffed and approved Intelnet I and II, which would allow Equatorial world-wide networking.[22] Technically, Equatorial is capable of internetworking through gateways using the X.75 protocol; however, agreements with foreign PTTs would be required in order to satisfy any regulatory problems that currently exist.[23]

Access Facilities. Equatorial meets this requirement by supporting IBM 3270 and X.25 synchronous protocol connections as well as many others.

Network Management and Control. Equatorial's Network Control Center operates around the clock, seven days a week to aid network operation, monitoring, and diagnostic analysis which includes remote control and checkout of individual micro earth station subsystems.[24] Monitoring systems measure signals for strength and interference and initiate alarms when required, aid in error detection and correction, and provide summary and status reports of overall network performance.[25]

Network Maintenance. Equatorial has a nationwide Field Service Organization which installs and maintains the earth stations. With more than a hundred maintenance sites across the nation, repairs to, or replacement of, micro earth stations can be accomplished any day of the week in a relatively short period of time. Due to the quality and quantity of Equatorial's maintenance services, it takes less than four business hours to provide on-site coverage for repairs to network equipment.[26] Although not stated specifically, preventive maintenance on the PSDN should not hamper normal operations.

System Security. Security is inherent on the Equatorial network because of the spread spectrum technology used. It was initially developed by the military to reduce the possibility of interference and increase the security of transmitted information.[27] In addition to the spread spectrum transmission techniques used, the customer network manager is capable of unique address to determine which micro earth stations are eligible to receive data. The network manager is capable of on the spot changes to a receiver's eligibility to collect data. Since the coding that allows individual micro earth stations to receive data is not accessible to the end user, tampering for the purpose of gathering unauthorized information is almost impossible.[28] Despite

the extensive security, Equatorial does not provide specific identification codes and passwords and therefore does not meet this SARNET requirement.

Network Usage Reports. The cost of Equatorial services is not based on usage but rather on the number of earth stations connected to the network.[29] Since billing is not a function of the amount of traffic over the network, detailed connection reports may not be required; however, as it is presently stated, Equatorial does not meet this requirement.

Summary. Equatorial fails to meet some of the specific requirements of the SARNET system. The average delay through the network, system security procedures, and possibly the bit error rate are the three areas that do not meet the SARNET requirements. It is still possible, however, for Equatorial to be considered for the final SARNET system if the pilot program shows that less stringent requirements for certain specifications can be tolerated. International connectivity is another area that needs further study to determine Equatorial's ability to meet this vital requirement.

NOTES

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2. Draft Statement of Work for procurement of GTE Telenet packet-switched data network services for NOAA, p. 11.

3. Ibid., p. 12.

4. Ibid., p. 10.

5. Ibid., p. 7.

6. The DDN Course, p. 9-3.

7. Ibid., p. 9-2.

8. Howard Grizzle II, Jon A. Keeneth, Dennis Lengyel, Stefanie Slachman, and Ann E. Smith, Federal Computer Performance Evaluation and Simulation Center, Network Integration Plan 83025-03-DOT, (Washington D. C.), September 1985, p. II-46.

9. The DDN Course, p. 5-27.

10. Ibid., p. 5-30.

11. Switched and Nonswitched Transmission Facilities, pp. TC23-441MM-102 -108.

12. Telenet Public Data Network Proposal Boilerplate, p. 30.

13. International Data Communication Services from GTE Telenet, p. 2.

14. Telenet Public Data Network Proposal Boilerplate, p. 6.

15. Ibid., p. 19.

16. Ibid., p. 8.

17. Switched and Nonswitched Transmission Facilities, pp. TC23-441MM-107.

18. Telenet Public Data Network Proposal Boilerplate, pp. 10-11.

19. *Ibid.*, pp. 12-13.

20. *Ibid.*, p. 44.

21. Letter from H. J. Walker, Director, International Marketing, Equatorial Communications Company, to Mr. Ron Barrett, Barrett Consulting, 15 July, 1986.

22. *Ibid.*

23. Francois Le, Program Manager, Equatorial Communications Company, telephone conversation with Brian Livie, 30 October, 1986.

24. *Equastar Satellite Transaction Network*.

25. *Equastar Satellite Communication Services*.

26. *Equastar Satellite Transaction Network*.

27. *Point-To-Multipoint Data Communication Network Services*.

28. *Equastar Satellite Communication Services*.

29. Francois Le, *Telephone conversation*.

CHAPTER IV

CONCLUSIONS AND RECOMMENDATIONS

The technical evaluation of packet-switched data networks is a complex and difficult task. There are many cost/performance trade-offs that must be made. Even after removing the cost factor, the analysis of network performance remains difficult. This study has focused on the evaluation of performance data and now presents its conclusions and recommendations.

Conclusions

Chapter II discussed the performance data of each representative network for the three different implementation strategies being considered. After detailing each network's performance specifications, this information was correlated and compared. Finally, the American National Standard X3.102 performance parameters were introduced and the compliance by each network with this standard discussed. Chapter III listed the requirements for the SARNET system and then evaluated each network based on its ability to meet these requirements.

In the above process, many obvious yet interesting observations were made. These observations are discussed below.

Performance Analysis

The first major conclusion resulting from this study is that it is extremely difficult to compare different networks based on performance. This is illustrated by the following facts.

Networks are hesitant to provide detailed performance specifications for their systems. Our request for information was not in the form of an RFP and was without the intent to procure network services; therefore, it is understandable why more detailed information was not provided. However, when performing a preliminary evaluation of available services, users often face a similar situation. Information provided in these instances is usually general in nature, comes in the form of advertisement brochures, and is often the only data available to the user.

Some networks contend that specific performance data is not advertised because it is constantly changing.[1] There may be other reasons for this as well. Networks may not have this detailed information or they may simply not wish to advertise it.

Performance specifications do not always correlate from network to network. As the Performance Comparisons section of Chapter II points out, data provided by one network was not necessarily provided by the others. An example is the DDN's specification of the probability of accidental misdelivery of a data unit and Telenet's specification of grade of service. These specifications did not correlate with anything provided by the other networks.

When specifications do correlate, they do not always have the same meaning. In the Performance Comparisons section of Chapter II, it was shown that there were four specifications that each network felt important enough to mention: data rates, delay, bit error rate, and availability. However, in the cases of delay, bit error rate, and availability, the meaning of the specification provided was not always the same from network to network.

The second major conclusion is that the American National Standard X3.102, which provides a uniform means of specifying the performance of data communications systems and services, is not widely used. This is supported by the following observations.

Networks are not complying with American National Standard X3.102. In Chapter II, under the National

Standard Comparison section, it was shown that the representative networks did not provide performance data which easily correlated to the ANS X3.102 performance parameters. In addition, a majority of the ANS X3.102 parameters were not even addressed by the networks. This lack of correlation and failure to specify all the parameters is illustrated in Table 2-8 at the end of Chapter II. The network compliance analysis showed that Equatorial, Telenet, and the DDN complied with the standard's parameters 17.6%, 20.6%, and 23.5% of the time respectively.

Users as well as members of the PSDN community do not appear to be fully aware of ANS X3.102. This is based upon conversations with the NOAA and USCG analysts responsible for the procurement of these services, as well as system engineers and network managers of the representative networks. Knowledge of ANS X3.102 is not evident at these levels but this does not imply that no one in these organizations is aware of the standard. In fact, Telenet was represented on the committee that helped develop ANS X3.102.[2]

Although this study indicates an apparent lack of knowledge of ANS X3.102 within the PSDN community, there is evidence that this situation is changing. The Institute for Telecommunication Sciences' Annual Technical Progress Report for 1985 states that Tymnet,

another commercial terrestrial-based PSDN, now offers Federal user organizations procurement specifications conforming to the X3.102 standard.[3] While not considered in this study, it would have been interesting to have included Tymnet's performance specifications in this evaluation.

Knowledge of ANS X3.102 does not ensure its use. This is evidenced by the fact than Telenet helped develop the standard, yet is not complying with it. Furthermore, "No one will comply with the standard unless they are forced to use it."[4] One reason for this appears to be the large financial investment that would be necessary to measure data transfer parameters for an entire, large and complex data network.[5]

SARNET Application

The third major conclusion is that the way requirements are written affects the evaluation process. The following facts support this observation.

Comparing network performance specifications, for user requirements which are not based on a standard, is difficult. For the SARNET pilot system, only three performance requirements were specified. Had ANS X3.102 been used as a guideline, additional requirements, which would have aided in the selection process, could have

been specified. As previously discussed, networks do not always provide their performance specifications in a standardized manner. Unless the user requires the networks to provide their specifications in a standard form, this information will have little meaning and be hard to compare. For example, the SARNET specifications for Bit Error Rate and Delay are not detailed enough to require a useful response from a PSDN. By using ANS X3.102, network responses to the requirements will have more meaning and be easier to compare.

<u>By writing the performance requirements to match those of a specific provider, the evaluation of alternatives is greatly restricted</u>. As seen in the evaluation of alternatives in Chapter III, the SARNET requirements were specifically written to procure the services of Telenet. Because of the need to begin the demonstration and evaluation process as soon as possible, the procurement of PSDN services from Telenet is understandable. However, in doing so, the requirements for Bit Error Rate and Delay basically eliminated all satellite-based PSDNs from consideration.

The fourth and final major conclusion is that it is difficult to select a PSDN strategy for the SARNET application. This is supported by all of the reasons discussed above in addition to the observations below.

The comparison of networks is difficult as it is; comparing different implementation strategies further compounds this problem. This study compared three completely different PSDN strategies: military, commercial land-based, and commercial satellite-based. Inherent differences in the implementation of each of these network strategies put limitations on the performance that each can provide. The military PSDN must provide for the specific requirements of precedence, preemption, security and survivability. The commercial satellite-based PSDN by its very nature has several built-in limitations to its Bit Error Rate and Delay performance measurements. These limitations directly affect the performance provided by these networks and compound the problem of comparison.

Based on the results of this study, only the commercial land-based PSDN meets the SARNET requirements. The military PSDN met all of the performance requirements for the SARNET system; however, other non-performance considerations eliminated it from further consideration. The commercial satellite-based PSDN failed to meet the SARNET's stringent requirements for Bit Error Rate and Delay. Although the commercial land-based PSDN met all of the requirements for the SARNET system, it is difficult to make a recommendation based on this alone. Until the demonstration and evaluation of the pilot

SARNET system is complete and more precise performance requirements are determined, a fair evaluation of a satellite-based PSDN cannot be made.

Recommendations

Having made the above conclusions, the following recommendations are offered.

Packet-Switched Data Networks should standardize their performance specifications. There were four performance specifications common to each of the networks. As a minimum, there should be an attempt to standardize the measurement and presentation of these specifications.

ANS X3.102 already exists; networks should use it to provide a uniform means of specifying performance requirements. This standard was developed over several years with the assistance of representatives from the PSDN community. Hal Folts, a noted expert in the field of standards, called ANS X3.102 an "outstanding start" and a good beginning for ensuring the quality of PSDN services.[6] A report on the impact of Federal Standard 1033, by A. G. Hanson in the spring of 1985, indicated that providers saw the potential for advantageous returns to them and their customers resulting from the Federal adoption of ANS X3.102.[7]

ANS X3.102 should be used as guide in preparing performance specifications for user requirements. Networks cannot be expected to adhere to this standard unless required to do so by the user.

Users should measure the performance they receive from their PSDN. If users do not take steps to measure the quality of the service they receive, they cannot be assured of getting what they pay for. It appears that users may typically overstate their requirements in an attempt to get adequate service. Consequently, they may be paying for more performance than they are actually receiving.

By using the standard to create realistic performance requirements, and then measuring to ensure that performance is met, users can avoid this situation.

A satellite-based Packet-Switched Data Network should be considered for the SARNET system if warranted by D&E results. Do not exclude the satellite-based PSDN option without considering the results of the D&E. The demonstration and evaluation of the pilot system should be an invaluable tool in fine-tuning the actual SARNET requirements and, since ANS X3.102 has been adopted as Federal Standard 1033, it should be used during this process.

Areas For Further Study

This study was purposely limited. However, several areas of our research introduced interesting possibilities for further study. They are presented here.

* How do advertised performance specifications compare to actual measured performance?
* From a user's standpoint, are all of the parameters presented in ANS X3.102 really required?
* What costs are involved in measuring network performance?
* What are the problems involved in international networking of a satellite-based PSDN?

NOTES

1. Powers, Interview.

2. Hal Folts, President, Omnicom, Inc., telephone conversation with Brian Livie, 31 October, 1986.

3. Institute for Telecommunications Sciences, National Telecommunications and Information Administration, U. S. Department of Commerce, Institute for Telecommunications Sciences Annual Technical Progress Report for 1985, (Boulder, Colorado), 1985, p. 92.

4. Francois Le, Telephone conversation.

5. A. G. Hanson, Institute for Telecommunication Sciences, National Telecommunications and Information Administration, U. S. Department of Commerce, Impact Assessment of Proposed Federal Standard 1033, (Boulder, Colorado), March, 1985, p. 68.

6. Hal Folts, Telephone conversation.

7. Hanson, p. 67.

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APPENDIX A

GLOSSARY OF TERMS AND ACRONYMS

AFB - Air Force Base

ANS - American National Standard

ANSI - American National Standard Institute

AUTODIN - Automatic Digital Network

bps - bits per second

CCITT - International Telephone and Telegraph Consultative Committee

CGD - Coast Guard District

CMCC - Canadian Mission Control Center

CNES - Centre National D'Etudes Spatiales (France)

CONUS - Continental United States

COSPAS - Space System for Search of Vessels in Distress (Soviet acronym - literally translated)

DAF - Dedicated Access Facility

DARPA - Defense Advanced Research Projects Agency

dB - Decibel

DCA - Defense Communications Agency

DDN - Defense Data Network

DDS - Digital Dataphone Service

D&E - Demonstration and Evaluation

DOC - Department of Communication (Canada)

FMCC - French Mission Control Center

Hz - Hertz (cycles per second)

IBM - International Business Machines

I/O - Input / Output

IP - Internet Protocol

IPD - Information Processing Division (NOAA/NESDIS)

LUT - Local User Terminal

MCC - Mission Control Center

MORFLOT - Ministry of Merchant Marine (Soviet Union)

ms - millisecond

NASA - National Aeronautics and Space Administration

NESDIS - National Environmental Satellite, Data, and Information Service

NOAA - National Oceanic and Atmospheric Administration

PAD - Packet Assembler/Disassembler

PDN - Public Data Network

PSDN - Packet Switched Data Network

RCC - Rescue Coordination Center

RFP - Request for Proposal

SAR - Search and Rescue

SARNET - Search and Rescue Data Communication Network

SARSAT - Search and Rescue Satellite Aided Tracking

SEDL - Systems Experimental Development Laboratory

SOW - Statement of Work

TAC - Terminal Access Controller

TCO - Telenet Central Office

TCP - Transmission Control Protocol

TCP/IP - Transmission Control Protocol/Internet Protocol

TEMPEST - Investigations of compromising emanations

TP - Telenet Processor

TPRF - Telenet Processor Reporting Facilities

USAF - United States Air Force

USCG - United States Coast Guard

USMCC - United States Mission Control Center

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